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CYCAS REVOLUTA (see page 311). (*Frontispiece.*)

PREFACE.

THE present book is the result of a revision and elaboration of the author's "Elementary Botany," New York, 1898. The general plan of the parts on physiology and general morphology remains unchanged. A number of the chapters in the physiological part are practically untouched, while others are thoroughly revised and considerable new matter is added, especially on the subjects of nutrition and digestion. The principal chapters on general morphology are unchanged or only slightly modified, the greatest change being in a revision of the subject of the morphology of fertilization in the gymnosperms and angiosperms in order to bring this subject abreast of the discoveries of the past few years. One of the greatest modifications has been in the addition of chapters on the classification of the algæ and fungi with studies of additional examples for the benefit of those schools where the time allowed for the first year's course makes desirable the examination of a broader range of representative plants. The classification is also carried out with greater definiteness, so that the regular sequence of classes, orders, and families is given at the close of each of the subkingdoms. Thus all the classes, all the orders (except a few in the algæ), and many of the families, are given for the algæ, fungi, mosses, liverworts, pteridophytes, gymnosperms, and angiosperms.

But by far the greatest improvement has been in the complete reorganization, rewriting, and elaboration of the part dealing with ecology, which has been made possible by studies of the past few years, so that the subject can be presented in a more logical and coherent form. As a result the subject-matter of

the book falls naturally into five parts, which may be passed in review as follows:

Part I. *Physiology.* This deals with the life processes of plants, as absorption, transpiration, conduction, photosynthesis, nutrition, assimilation, digestion, respiration, growth, and irritability. Since protoplasm is fundamental to all the life work of the plant, this subject is dealt with first, and the student is led through the study of, and experimentation with, the simpler as well as some of the higher plants, to a general understanding of protoplasm and the special way in which it enables the plant to carry on its work and to adjust itself to the conditions of its existence. This study also serves the purpose of familiarizing the pupil with some of the lower and unfamiliar plants.

Some teachers will prefer to begin the study with general morphology and classification, thus studying first the representatives of the great groups of plants, and others will prefer to dwell first on the ecological aspects of vegetation. This can be done in the use of this book by beginning with Part II or with Part III.

But the author believes that morphology can best be comprehended after a general study of life processes and functions of the different parts of plants, including in this study some of the lower forms of plant life where some of these processes can more readily be observed. The pupil is then prepared for a more intelligent consideration of general and comparative morphology and relationships. Even more important is a first study of physiology before taking up the subject of ecology. The great value to be derived from a study of plants in their relation to environment lies in the ability to interpret the different states, conditions, behavior, and associations of the plant, and for this physiology is indispensable. It is true that a considerable measure of success can be obtained by a good teacher in beginning with either subject, but the writer believes that measure of success would be greater if the subjects were taken up in the order presented here.

Part II. *Morphology and life history of representative plants.*

This includes a rather careful study of representative examples among the algæ, fungi, liverworts, mosses, ferns and their allies, gymnosperms and angiosperms, with especial emphasis on the form of plant parts, and a comparison of them in the different groups, with a comparative study of development, reproduction, and fertilization, rounding out the work with a study of life histories and noting progression and retrogression of certain organs and phases in proceeding from the lower to the higher plants. Thus, in the algæ a first critical study is made of four examples which illustrate in a marked way progressive stages of the plant body, sexual organs, and reproduction. Additional examples are then studied for the purpose of acquiring a knowledge of variations from these types and to give a broader basis for the brief consideration of general relationships and classification.

A similar plan is followed in the other great groups. The processes of fertilization and reproduction can be most easily observed in the lower plants like the algæ and fungi, and this is an additional argument in favor of giving emphasis to these forms of plant life as well as the advantage of proceeding logically from simpler to more complex forms. Having also learned some of these plants in our study of physiology, we are following another recognized rule of pedagogy, i.e., proceeding from known objects to unknown structures and processes. Through the study of the organs of reproduction of the lower plants and by general comparative morphology we have come to an understanding of the morphology of the parts of the flower, and of the true sexual organs of the seed plants, and no student can hope to properly interpret the significance of the flower, or the sexual organs of the seed plants who neglects a careful study of the general morphology of the lower plants.

Part III. *Plant members in relation to environment.* This part deals with the organization of the plant body as a whole in its relation to environment, the organization of plant tissues with a discussion of the principal tissues and a descriptive synopsis of the same. This is followed by a complete study from a biological

standpoint of the different members of the plant, their special function and their special relations to environment. The stem, root, leaf, flower, etc., are carefully examined and their ecological relations pointed out. This together with the study of physiology and representatives in the groups of plants forms a thorough basis for pure plant ecology, or the special study of vegetation in its relation to environment.

Part IV. *Vegetation in relation to environment.* This part deals with pure plant ecology in its general aspects, or vegetation forms in relation to environment. First there is a study of the factors of environment or ecological factors, which in general are grouped under the physical, climatic, and biotic factors. This is followed by the laws of migration, the analysis of vegetation forms and structures, plant formations and societies. Then in order are treated forest societies, prairie societies, desert societies, arctic and alpine societies, aquatic societies, and the special societies of sandy, rocky, and marshy places. This part closes with some practical suggestions for the study of plant formations, and a description of the principal vegetation regions of the earth.

Part V. *Representative families of angiosperms.* Topics for study of additional examples of angiosperms are outlined here. It is not intended that this shall follow Part IV in the course, but where the teacher desires to study more examples than are given in Part II these topics or chosen ones can be studied along with or following Part III. The work of Part IV can usually be well undertaken by field excursions in conjunction with the work of Part III, and this would naturally be handled in the spring, with Part I in the autumn and Part II in the winter.

Acknowledgments. The author wishes to express his gratefulness to all those who have given aid in the preparation of this work, or of the earlier editions of Elementary Botany; to his associates, Dr. E. J. Durand, Dr. K. M. Wiegand, and Professor W. W. Rowlee, of the botanical department, and to Professor B. M. Duggar of the University of Missouri, Professor J. C. Arthur of Purdue University, and Professor W. F. Ganong of

Smith College, for reading one or more portions of the text; as well as to all those who have contributed illustrations.

Illustrations. The large majority of the illustrations are new (or are the same as those used in earlier editions of the author's Elementary Botany) and were made with special reference to the method of treatment followed in the text. Many of the photographs were made by the author. Others were contributed by President P. H. Mell of the Clemson Agricultural College; Professor Rowlee of Cornell University; Mr. H. J. Webber, Washington, D. C.; Mr. John Gifford of New Jersey; Professor B. M. Duggar, University of Missouri; Mr. Herman von Schrenk, Missouri Botanical Garden; Professor H. C. Cowles of the University of Chicago; Professor C. E. Bessey, University of Nebraska; Dr. M. B. Howe, New York Botanical Garden; Mr. Gifford Pinchot, Chief of the Bureau of Forestry; Mr. B. T. Galloway, Chief of the Bureau of Plant Industry; Professor Trelease, Missouri Botanical Garden; Professor Tuomey of Yale University; and Mr. E. H. Harriman, who through Dr. C. H. Merriam of the National Museum allowed the use of several of his copyrighted photographs from Alaska. To those who have contributed drawings the author is indebted as follows: to Professor Margaret C. Ferguson, Wellesley College; Professor Bertha Stoneman of Huguenot College, South Africa; Mr. H. Hasselbring of Chicago; Dr. K. Miyake, formerly of Cornell University and now of Doshisha College, Japan; and Professors Ikeno and Hirase of the Tokio Imperial University. The author is also indebted to Ginn & Co., Boston, for the privilege to use from his "First Studies of Plant Life" the following figures: 28, 29, 46, 48, 49, 56, 62, 66, 67, 87, 102, 103, 422–426, 429, 430, 438–440, 443, 444, 448, 449, 452, 472–475, 486, 496*b*, 514*a*, 514*b*. A few others are acknowledged in the text.

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TABLE OF CONTENTS.

PART I. PHYSIOLOGY.

CHAPTER I.

PAGE
PROTOPLASM. 1

CHAPTER II.

ABSORPTION, DIFFUSION, OSMOSE. 13

CHAPTER III.

HOW PLANTS OBTAIN WATER. 22

CHAPTER IV.

TRANSPIRATION, OR THE LOSS OF WATER BY PLANTS. 35

CHAPTER V.

PATH OF MOVEMENT OF WATER IN PLANTS. 48

CHAPTER VI.

MECHANICAL USES OF WATER. 56

CHAPTER VII.

STARCH AND SUGAR FORMATION. 60
1. The Gases Concerned. 60
2. Where Starch is Formed. 64
3. Chlorophyll and the Formation of Starch. 67

CHAPTER VIII.

STARCH AND SUGAR CONCLUDED; ANALYSIS OF PLANT SUBSTANCE. . . . 73
1. Translocation of Starch. 73
2. Sugar, and Digestion of Starch. 75
3. Rough Analysis of Plant Substance. 79

CHAPTER IX.

PAGE
How Plants Obtain their Food, I. 81
1. Sources of Plant Food 81
2. Parasites and Saprophytes 83
3. How Fungi Obtain their Food 86
4. Mycorhiza 91
5. Nitrogen-gatherers 92
6. Lichens 93

CHAPTER X.

How Plants Obtain their Food, II. 97
Seedlings, 97. Digestion, 107. Assimilation 109

CHAPTER XI.

Respiration 110

CHAPTER XII.

Growth 118

CHAPTER XIII.

Irritability 125

PART II. MORPHOLOGY AND LIFE HISTORY OF REPRESENTATIVE PLANTS.

CHAPTER XIV.

Spirogyra 136

CHAPTER XV.

Vaucheria 142

CHAPTER XVI.

Œdogonium 147

CHAPTER XVII.

Coleochæte 153

CHAPTER XVIII.

Classification and Additional Studies of the Algæ 158

CHAPTER XIX.

Fungi: Mucor and Saprolegnia 177

CHAPTER XX.

PAGE
Fungi Continued ("Rusts" Uredineæ)..... 187

CHAPTER XXI.

The Higher Fungi..... 195

CHAPTER XXII.

Classification of the Fungi..... 213

CHAPTER XXIII.

Liverworts (Hepaticæ)..... 222
Riccia, 222. Marchantia..... 226

CHAPTER XXIV.

Liverworts Continued..... 231
Sporogonium of Marchantia..... 231
Leafy-stemmed Liverworts..... 236
The Horned Liverworts..... 240
Classification of the Liverworts..... 242

CHAPTER XXV.

Mosses (Musci)..... 243
Classification of Mosses..... 248

CHAPTER XXVI.

Ferns..... 251

CHAPTER XXVII.

Ferns Continued..... 262
Gametophyte of Ferns..... 262
Sporophyte..... 268

CHAPTER XXVIII.

Dimorphism of Ferns..... 273

CHAPTER XXIX.

Horsetails..... 280

CHAPTER XXX.

Club-mosses..... 284

CHAPTER XXXI.

Quillworts (Isoetes)..... 289

CHAPTER XXXII.

PAGE
FERNS AND THEIR RELATIVES. 292
of the Pteridophytes. 295

CHAPTER XXXIII.

GYMNOSPERMS 297

CHAPTER XXXIV.

FURTHER STUD ON GYMNOSPERMS. 311

CHAPTER XXXV.

MORPHOLOGY OF THE ANGIOSPERMS: TRILLIUM; DENTARIA. 318

CHAPTER XXXVI.

GAMETOPHYTE AND SPOROPHYTE OF ANGIOSPERMS. 325

CHAPTER XXXVII.

MORPHOLOGY OF THE NUCLEUS AND SIGNIFICANCE OF GAMETOPHYTE AND SPOROPHYTE. 340

PART III. PLANT MEMBERS IN RELATION TO ENVIRONMENT.

CHAPTER XXXVIII.

THE ORGANIZATION OF THE PLANT. 349
I. Organization of Plant Members. 349
II. Organization of Plant Tissues. 356

CHAPTER XXXIX.

THE DIFFERENT TYPES OF STEMS. 365
I. Erect Stems. 365
II. Creeping, Climbing, and Floating Stems. 369
III. Specialized Shoots and Shoots for Storage of Food. 372
IV. Annual Growth and Winter Protection of Shoots and Buds. . . 374

CHAPTER XL.

FOLIAGE LEAVES. 383
I. General Form and Arrangement of Leaves. 383
II. Protective Modifications of Leaves. 392
III. Protective Positions. 395
IV. Relation of Leaves to Light. 397
V. Leaf Patterns. 404

CHAPTER XLI.

PAGE
THE ROOT. 410
I. Function of Roots. 410
II. Kinds of Roots. 415

CHAPTER XLII.

THE FLORAL SHOOT. 419
I. The Parts of the Flower. 419
II. Kinds of Flowers. 421
III. Arrangement of Flowers, or Mode of Inflorescence. 426

CHAPTER XLIII.

POLLINATION 433

CHAPTER XLIV.

THE FRUIT. 450
I. Parts of the Fruit. 450
II. Indehiscent Fruits. 451
III. Dehiscent Fruits. 452
IV. Fleshy and Juicy Fruits. 454
V. Reinforced, or Accessory, Fruits. 455
VI. Fruits of Gymnosperms. 456
VII. "Fruit" of Ferns, Mosses, etc. 457

CHAPTER XLV.

SEED DISPERSAL. 458

PART IV. VEGETATION IN RELATION TO ENVIRONMENT.

CHAPTER XLVI.

FACTORS INFLUENCING VEGETATION TYPES; OR ECOLOGICAL FACTORS . 464
I. Physical Factors. 465
II. Climatic Factors. 477
III. Biotic Factors. 479

CHAPTER XLVII.

VEGETATION TYPES AND STRUCTURES. 482
I. Warming's Vegetation Types. 483
II. Schimper's Vegetation Types. 485
III. Plant Structures adapted to Conditions of Environment. . . . 486

CHAPTER XLVIII.

PAGE
LAWS AND LIMITS OF PLANT MIGRATION. 497
I. Relation of Plants to Earth's Surface as a Whole. 498
II. Life Regions, Zones, and Areas. 500
III. Methods and Causes of Plant Migration. 506

CHAPTER XLIX.

PLANT FORMATIONS. 515
I. Climatic Formations. 515
II. Edaphic Formations. 518
III. Aquatic Formations. 521
IV. Culture Formations. 521
V. Principal and Individual Formations. 522

CHAPTER L.

FOREST SOCIETIES. 529
I. General Character of Forest Societies. 529
II. Boreal Forests. 534
III. Austral Forests. 535
IV. Tropical Forests. 541
V. Relation of Forests to Rainfall. 546
VI. Forest Regeneration and Protection. 548

CHAPTER LI.

THE PRAIRIE AND PLAINS SOCIETIES. 556
I. Grassland Formations. 556
II. Prairie Formations. 557
III. The Plains Formations. 559
IV. Edaphic Formations in the Prairie Region. 560

CHAPTER LII.

DESERT PLANT SOCIETIES. 565
I. Characters of True Desert Plants. 565
II. The Sonora-Nevada Desert. 568
III. Other Desert Regions. 573

CHAPTER LIII.

ARCTIC AND ALPINE PLANT SOCIETIES. 576
I. Arctic Plant Societies. 576
II. Alpine Plant Societies. 582

CHAPTER LIV

PAGE
THE VEGETATION OF THE STRAND. 586
I Types of Strand. 586
II. The Vegetation of the Beach or Strand. 588
III. Vegetation of the Dunes 592

CHAPTER LV.

PLANT SOCIETIES OF ROCKY AREAS, MEADOWS, AND MARSHES 600
I. Vegetation of Rocky Places, and New Land 600
II. Vegetation of Swamps and Moors. 606

CHAPTER LVI.

AQUATIC PLANT SOCIETIES 620
I. General Considerations. 620
II. Fresh-water, or Limnetic, Plant Societies. 624
III. Marine, or Pelagic, Plant Societies 627

CHAPTER LVII.

PRACTICAL STUDY OF PLANT FORMATIONS. 630
I. Suggestions for Practical Study of Plant Formations 630
II. Natural Vegetation Regions of the Earth. 638

PART V. REPRESENTATIVE FAMILIES OF ANGIOSPERMS.

CHAPTER LVIII.

RELATION OF SPECIES, GENUS, FAMILY, ORDER, ETC. 648

CHAPTER LIX.

MONOCOTYLEDONS. 654

CHAPTER LX.

MONOCOTYLEDONS CONCLUDED. 662

CHAPTER LXI.

DICOTYLEDONS. 667

CHAPTER LXII.

DICOTYLEDONS CONTINUED 672

CHAPTER LXIII.

PAGE
DICOTYLEDONS CONTINUED 678

CHAPTER LXIV.

DICOTYLEDONS CONTINUED 687

CHAPTER LXV.

DICOTYLEDONS CONCLUDED 694

CHAPTER LXVI.

CLASSIFICATION OF THE ANGIOSPERMS 702
I. Class Monocotyledones 702
II. Class Dicotyledones 704

APPENDIX 713
INDEX 725

PART I.

PHYSIOLOGY.

CHAPTER I.

PROTOPLASM.*

1. In the study of plant life and growth, it will be found convenient first to inquire into the nature of the substance which we call the living material of plants. For plant growth, as well as some of the other processes of plant life, are at bottom dependent on this living matter. This living matter is called in general *protoplasm*.

2. In most cases protoplasm cannot be seen without the help of a microscope, and it will be necessary for us here to employ one if we wish to see protoplasm, and to satisfy ourselves by examination that the substance we are dealing with *is* protoplasm.

3. We shall find it convenient first to examine protoplasm in some of the simpler plants; plants which from their minute size and simple structure are so transparent that when examined with the microscope the interior can be seen.

For our first study let us take a plant known as *spirogyra*, though there are a number of others which would serve the purpose quite as well, and may quite as easily be obtained for study.

* For apparatus, reagents, collection and preservation of material, etc., see Appendix.

Protoplasm in spirogyra.

4. The plant spirogyra.—This plant is found in the water of pools, ditches, ponds, or in streams of slow-running water. It is green in color, and occurs in loose mats, usually floating near the surface. The name "pond-scum" is sometimes given to this plant, along with others which are more or less closely related. It is an *alga*, and belongs to a group of plants known as *algæ*. If we lift a portion of it from the water, we see that the mat is made up of a great tangle of green silky threads. Each one of these threads is a plant, so that the number contained in one of these floating mats is very great.

Let us place a bit of this thread tangle on a glass slip, and examine with the microscope and we will see certain things about the plant which are peculiar to it, and which enable us to distinguish it from other minute green water plants. We shall also wish to learn what these peculiar parts of the plant are, in order to demonstrate the protoplasm in the plant.*

5. Chlorophyll bands in spirogyra.—We first observe the presence of bands; green in color, the edges of which are usually very irregularly notched. These bands course along in a spiral manner near the surface of the thread. There may be one or several of these spirals, according to the species which we happen to select for study. This green coloring matter of the band is *chlorophyll*, and this substance, which also occurs in the higher green plants, will be considered in a later chapter. At quite regular intervals in the chlorophyll band are small starch grains, grouped in a rounded mass enclosing a minute body, the *pyrenoid*, which is peculiar to many algæ.

6. The spirogyra thread consists of cylindrical cells end to end.—Another thing which attracts our attention, as we examine a thread of spirogyra under the microscope, is that the thread is

*If spirogyra is forming fruit some of the threads will be lying parallel in pairs, and connected with short tubes. In some of the cells there will be found rounded or oval bodies known as *zygospores*. These may be seen in fig. 86, and will be described in another part of the book.

made up of cylindrical segments or compartments placed end to end. We can see a distinct separating line between the ends. Each one of these segments or compartments of the thread is a *cell*, and the boundary wall is in the form of a cylinder with closed ends.

Fig. 1.

Thread of spirogyra, showing long cells, chlorophyll band, nucleus, strands of protoplasm, and the granular wall layer of protoplasm

7. Protoplasm.—Having distinguished these parts of the plant we can look for the protoplasm. It occurs within the cells. It is colorless (i.e., hyaline) and consequently requires close observation. Near the center of the cell can be seen a rather dense granular body of an elliptical or irregular form, with its long diameter transverse to the axis of the cell in some species; or triangular, or quadrate in others. This is the *nucleus*. Around the nucleus is a granular layer from which delicate threads of a shiny granular substance radiate in a starlike manner, and terminate in the chlorophyll band at one of the pyrenoids. A granular layer of the same substance lines the inside of the cell wall, and can be seen through the microscope if it is properly focussed. This granular substance in the cell is *protoplasm*.

8. Cell-sap in spirogyra.—The greater part of the interior space of the cell, that between the radiating strands of protoplasm, is occupied by a watery fluid, the "cell-sap."

9. Reaction of protoplasm to certain reagents.—We can employ certain tests to demonstrate that this granular substance which we have seen is protoplasm, for it has been found, by repeated experiments with a great many kinds of plants, that protoplasm gives a definite reaction in response to treatment with certain substances called reagents. Let us mount a few threads of the spirogyra in a drop of a solution of iodine, and observe the

results with the aid of the microscope. The iodine gives a yellowish-brown color to the protoplasm, and it can be more distinctly seen. The nucleus is also much more prominent since it colors deeply, and we can perceive within the nucleus one small rounded body, sometimes more, the *nucleolus*. The iodine here kills and stains the protoplasm. The protoplasm, however, in a living condition will resist for a time some other reagents, as we shall see if we attempt to stain it with a one per cent aqueous solution of a dye known as *eosin*. Let us mount a few living threads in such a solution of eosin, and after a time wash off the stain. The protoplasm remains uncolored. Now let us place these threads for a short time, two or three minutes, in strong alcohol, which kills the protoplasm. Then mount them in the eosin solution. The protoplasm now takes the eosin stain. After the protoplasm has been killed we note that the nucleus is no longer elliptical or angular in outline, but is rounded. The strands of protoplasm are no longer in tension as they were when alive.

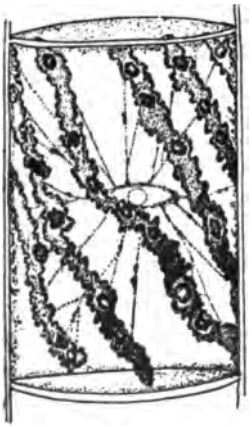

Fig. 2.
Cell of spirogyra before treatment with iodine.

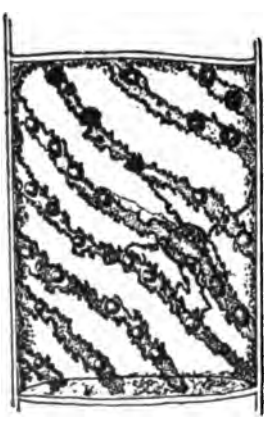

Fig. 3.
Cell of spirogyra after treatment with alcohol and iodine.

10. Let us now take some fresh living threads and mount them in water. Place a small drop of dilute glycerine on the slip at one side of the cover glass, and with a bit of filter paper at the other side draw out the water. The glycerine will flow under the cover glass and come in contact with the spirogyra threads. Glycerine absorbs water promptly. Being in contact with the threads it draws water out of the cell cavity, thus caus-

ing the layer of protoplasm which lines the inside of the cell wall to collapse, and separate from the wall, drawing the chlorophyll band inward toward the center also. The wall layer of protoplasm can now be more distinctly seen and its granular character observed.

Fig. 4.
Cell of spirogyra before treatment with glycerine.

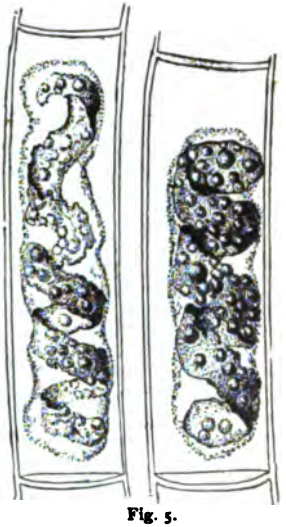

Fig. 5.
Cells of spirogyra after treatment with glycerine.

We have thus employed three tests to demonstrate that this substance with which we are dealing shows the reactions which we know by experience to be given by protoplasm. We therefore conclude that this colorless and partly granular, slimy substance in the spirogyra cell is protoplasm, and that when we have performed these experiments, and noted carefully the results, we have *seen* protoplasm.

11. Earlier use of the term protoplasm.—Early students of the living matter in the cell considered it to be alike in substance, but differing in density; so the term protoplasm was applied to all of this living matter. The nucleus was looked upon as simply a denser portion of the protoplasm, and the nucleolus as a still denser portion. Now it is believed that the nucleus is a distinct substance, and a permanent organ of the cell. The remaining portion of the protoplasm is now usually spoken of as the *cytoplasm*.

In spirogyra then the cytoplasm in each cell consists of a layer which lines the inside of the cell wall, a nuclear layer, which surrounds the nucleus, and radiating strands which connect the nucleus and wall layers, thus suspending the nucleus near the center of the cell. But it seems best in this elementary study to use the term protoplasm in its general sense.

Protoplasm in mucor.

12. Let us now examine in a similar way another of the simple plants with the special object in view of demonstrating the protoplasm. For this purpose we may take one of the plants belonging to the group of *fungi*. These plants possess no chlorophyll. One of several species of *mucor*, a common mould, is readily obtainable, and very suitable for this study.*

13. Mycelium of mucor.—A few days after sowing in some gelatinous culture medium we find slender, hyaline threads, which are very much branched, and, radiating from a central point, form circular colonies, if the plant has not been too thickly sown, as shown in fig. 6. These threads of the fungus form the *mycelium*. From these characters of the plant, which we can readily see without the aid of a microscope, we note how different it is from spirogyra.

To examine for protoplasm let us lift carefully a thin block of gelatine containing the mucor threads, and mount it in water on a glass slip. Under the microscope we see only a small portion of the branched threads. In addition to the absence of chlorophyll, which we have already noted, we see that the mycelium is not divided at short intervals into cells, but appears like a delicate tube with branches, which become successively smaller toward the ends.

14. Appearance of the protoplasm.—Within the tube-like thread now note the protoplasm. It has the same general appearance as that which we noted in spirogyra. It is slimy, or semi-fluid, partly hyaline, and partly granular, the granules consisting of minute particles (the *microsomes*). While in mucor the protoplasm has the same general appearance as in spirogyra, its arrangement is very different. In the first place it is plainly

* The most suitable preparations of mucor for study are made by growing the plant in a nutrient substance which largely consists of gelatine, or, better, agar-agar, a gelatinous preparation of certain seaweeds. This, after the plant is sown in it, should be poured into sterilized shallow glass plates, called Petrie dishes.

continuous throughout the tube. We do not see the prominent radiations of strands around a large nucleus, but still the proto-

Fig. 6.
Colonies of mucor.

plasm does not fill the interior of the threads. Here and there are rounded clear spaces termed *vacuoles*, which are filled with the watery fluid, cell-sap. The nuclei in mucor are very minute, and cannot be seen except after careful treatment with special reagents.

15 **Movement of the protoplasm in mucor.**—While examining the protoplasm in mucor we are likely to note streaming movements. Often a current is seen flowing slowly down one side of the thread, and another flowing back on the other side, or it may all stream along in the same direction.

16. **Test for protoplasm.**—Now let us treat the threads with a solution of iodine. The yellowish-brown color appears which is characteristic of protoplasm when subject to this reagent.

If we attempt to stain the living protoplasm with a one per cent aqueous solution of eosin it resists it for a time, but if we first kill the protoplasm with strong alcohol, it reacts quickly to the application of the eosin. If we treat the living threads with glycerine the protoplasm is contracted away from the wall, as we found to be the case with spirogyra. While the color,

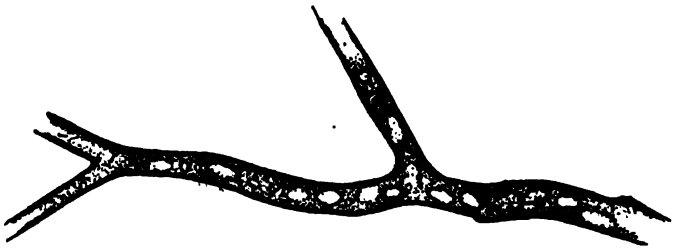

Fig. 7.
Thread of mucor, showing protoplasm and vacuoles.

form and structure of the plant mucor is different from spirogyra, and the arrangement of the protoplasm within the plant is also quite different, the reactions when treated by certain reagents are the same. We are justified then in concluding that the two plants possess in common a substance which we call protoplasm.

Protoplasm in nitella.

17. One of the most interesting plants for the study of one remarkable peculiarity of protoplasm is *Nitella*. This plant belongs to a small group known as stoneworts. They possess chlorophyll, and, while they are still quite simple as compared with the higher plants, they are much higher in the scale than spirogyra or mucor.

18. Form of nitella.—A common species of nitella is *Nitella flexilis*. It grows in quiet pools of water. The plant consists of a main axis, in the form of a cylinder. At quite regular intervals are whorls of several smaller thread-like outgrowths, which, because of their position, are termed "leaves," though they are not true leaves. These are branched in a characteristic fashion at the tip. The main axis also branches, these branches arising in the axil of a whorl, usually singly. The portions of the axis where the whorls arise are the *nodes*. Each node is made up of a number of small cells definitely arranged. The portion of the axis between two adjacent whorls is an inter-

node. These internodes are peculiar. They consist of but a single "cell," and are cylindrical, with closed ends. They are sometimes 5–10 cm. long.

19. Internode of nitella.—For the study of an internode of nitella, a small one, near the end, or the ends of one of the "leaves" is best suited, since it is more transparent. A small portion of the plant should be placed on the glass slip in water with the cover glass over a tuft of the branches near the growing end. Examined with the microscope the green chlorophyll bodies, which form oval or oblong discs, are seen to be very numerous. They lie quite closely side by side and form in perfect rows along the inner surface of the wall. One peculiar feature of the arrangement of the chlorophyll bodies is that there are two lines, extending from one end of the internode to the other on opposite sides, where the chlorophyll bodies are wanting. These are known as neutral lines. They run parallel with the axis of the internode, or in a more or less spiral manner as shown in fig. 9.

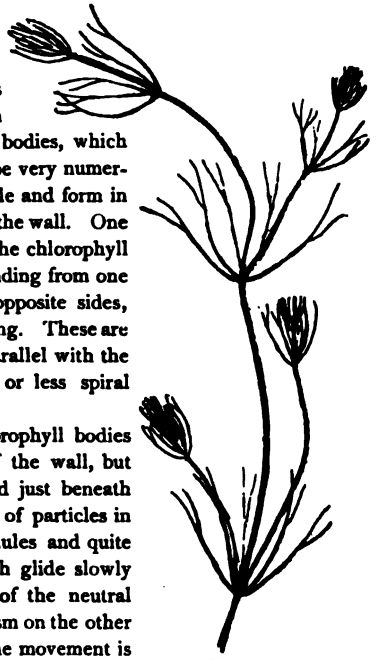

Fig. 8.
Portion of plant nitella.

20. Cyclosis in nitella.—The chlorophyll bodies are stationary on the inner surface of the wall, but if the microscope be properly focussed just beneath this layer we notice a rotary motion of particles in the protoplasm. There are small granules and quite large masses of granular matter which glide slowly along in one direction on a given side of the neutral line. If now we examine the protoplasm on the other side of the neutral line, we see that the movement is in the opposite direction. If we examine this movement at the end of an internode the particles are seen to glide around the end from one side of the neutral line to the other. So that when conditions are favorable, such as temperature, healthy state of the plant, etc., this gliding of the particles or apparent streaming of the protoplasm down one side of the "cell," and back upon the other, continues in an uninterrupted rotation, or *cyclosis*. There are many nuclei in an internode of nitella, and they move also.

21. Test for protoplasm.—If we treat the plant with a solution of iodine we get the same reaction as in the case of spirogyra and mucor. The protoplasm becomes yellowish brown.

22. Protoplasm in one of the higher plants.—We now wish to examine, and test for, protoplasm in one of the higher plants.

Young or growing parts of any one of various plants—the petioles of young leaves, or young stems of growing plants—are suitable for study. Tissue from the pith of corn (Zea mays) in young shoots just back of the growing point or quite near the joints of older but growing corn stalks furnishes excellent material.

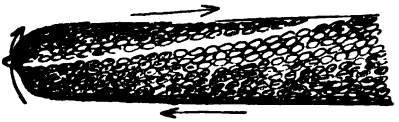

Fig. 9.
Cyclosis in nitella.

If we should place part of the stem of this plant under the microscope we should find it too opaque for observation of the interior of the cells. This is one striking difference which we note as we pass from the low and simple plants to the higher and more complex ones; not only in general is there an increase of size, but also in general an increase in thickness of the parts. The cells, instead of lying end to end or side by side, are massed together so that the parts are quite opaque. In order to study the interior of the plant we have selected it must be cut into such thin layers that the light will pass readily through them.

For this purpose we section the tissue selected by making with a razor, or other very sharp knife, very thin slices of it. These are mounted in water in the usual way for microscopic study. In this section we notice that the cells are polygonal in form. This is brought about by mutual pressure of all the cells. The granular protoplasm is seen to form a layer just inside the wall, which is connected with the nuclear layer by radiating strands of the same substance. The nucleus does not always lie at the middle of the cell, but often is near one side. If we now apply an alcohol solution of iodine the characteristic yellowish-brown color appears. So we conclude here also that this substance is identical with the living matter in the other very different plants which we have studied.

23. Movement of protoplasm in the higher plants.—Certain parts of the higher plants are suitable objects for the study of the so-called streaming movement of protoplasm, especially the delicate hairs, or thread-like outgrowths, such as the silk of

corn, or the delicate staminal hairs of some plants, like those of the common spiderwort, tradescantia, or of the tradescantias grown for ornament in greenhouses and plant conservatories.

Sometimes even in the living cells of the corn plant which we have just studied, slow streaming or gliding movements of the granules are seen along the strands of protoplasm where they radiate from the nucleus. See note at close of this chapter.

24. Movement of protoplasm in cells of the staminal hair of "spiderwort."—A cell of one of these hairs from a stamen of a tradescantia grown in glass houses is shown in fig. 10. The

Fig. 10.
Cell from stamen hair of tradescantia showing movement of the protoplasm.

nucleus is quite prominent, and its location in the cell varies considerably in different cells and at different times. There is a layer of protoplasm all around the nucleus, and from this the strands of protoplasm extend outward to the wall layer. The large spaces between the strands are, as we have found in other cases, filled with the cell-sap.

An entire stamen, or a portion of the stamen, having several hairs attached, should be carefully mounted in water. Care should be taken that the room be not cold, and if the weather is cold the water in which the preparation is mounted should be warm. With these precautions there should be little difficulty in observing the streaming movement.

The movement is detected by observing the gliding of the granules. These move down one of the strands from the nucleus along the wall layer, and in towards the nucleus in another strand. After a little the direction of the movement in any one portion may be reversed.

25. Cold retards the movement.—While the protoplasm is moving, if we rest the glass slip on a block of ice, the movement will become slower, or will cease altogether. Then if we

warm the slip gently, the movement becomes normal again. We may now apply here the usual tests for protoplasm. The result is the same as in the former cases.

26. Protoplasm occurs in the living parts of all plants.— In these plants representing such widely different groups, we find a substance which is essentially alike in all. Though its arrangement in the cell or plant body may differ in the different plants or in different parts of the same plant, its general appearance is the same. Though in the different plants it presents, while alive, varying phenomena, as regards mobility, yet when killed and subjected to well known reagents the reaction is in general identical. Knowing by the experience of various investigators that protoplasm exhibits these reactions under given conditions, we have demonstrated to our satisfaction that we have seen protoplasm in the simple alga, spirogyra, in the common mould, mucor, in the more complex stonewort, nitella, and in the cells of tissues of the highest plants.

27. By this simple process of induction of these facts concerning this substance in these different plants, we have learned an important method in science study. Though these facts and deductions are well known, the repetition of the methods by which they are obtained on the part of each student helps to form habits of scientific carefulness and patience, and trains the mind to logical processes in the search for knowledge.

28. While we have by no means exhausted the study of protoplasm, we can, from this study, draw certain conclusions as to its occurrence and appearance in plants. Protoplasm is found in the living and growing parts of all plants. It is a semi-fluid, or slimy, granular, substance; in some plants, or parts of plants, the protoplasm exhibits a streaming or gliding movement of the granules. It is irritable. In the living condition it resists more or less for some time the absorption of certain coloring substances. The water may be withdrawn by glycerine. The protoplasm may be killed by alcohol. When treated with iodine it becomes a yellowish-brown color.

Note. In some plants, like elodea for example, it has been found that the streaming of the protoplasm is often induced by some injury or stimulus, while in the normal condition the protoplasm does not move.

CHAPTER II.

ABSORPTION, DIFFUSION, OSMOSE.

29. We may next endeavor to learn how plants absorb water or nutrient substances in solution. There are several very instructive experiments, which can be easily performed, and here again some of the lower plants will be found useful.

30. Osmose in spirogyra.—Let us mount a few threads of this plant in water for microscopic examination, and then draw under the cover glass a five per cent solution of ordinary table salt (NaCl) with the aid of filter paper. We shall soon see that the result is similar to that which was obtained when glycerine was used to extract the water from the cell-sap, and to contract the protoplasmic membrane from the cell wall. But the process goes on evenly and the plant is not injured. The protoplasmic layer contracts slowly from the cell wall, and the movement of the membrane can be watched by looking through the microscope. The membrane contracts in such a way that all the contents of the cell are finally collected into a rounded or oval mass which occupies the center of the cell.

If we now add fresh water and draw off the salt solution, we can see the protoplasmic membrane expand again, or move out in all directions, and occupy its former position against the inner surface of the cell wall. This would indicate that there is some pressure from within while this process of absorption is going on, which causes the membrane to move out against the cell wall.

The salt solution draws water from the cell-sap. There is thus a tendency to form a vacuum in the cell, and the pressure on the outside of the protoplasmic membrane causes it

to move toward the center of the cell. When the salt solution is removed and the thread of spirogyra is again bathed with water, the movement of the water is *inward* in the cell. This would suggest that there is some substance dissolved in the cell-sap which does not readily filter out through the membrane, but draws on the water outside. It is this which produces the pressure from within and crowds the membrane out against the cell wall again.

Fig. 11.
Spirogyra before placing in salt solution.

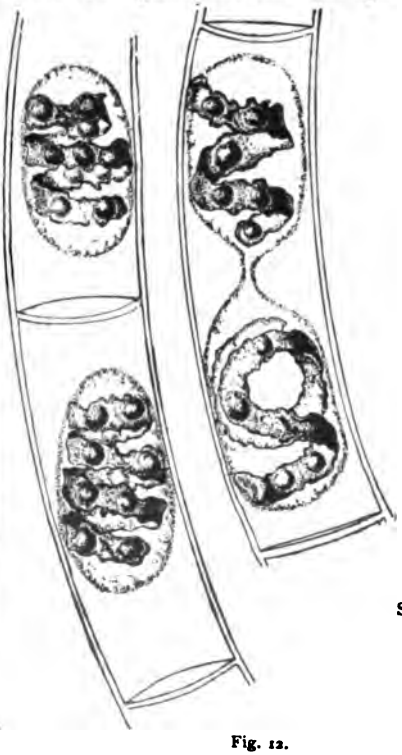

Fig. 12.
Spirogyra in 5% salt solution.

Fig. 13.
Spirogyra from salt solution into water.

31. Turgescence.—Were it not for the resistance which the cell wall offers to the pressure from within, the delicate proto-

plasmic membrane would stretch to such an extent that it would be ruptured, and the protoplasm therefore would be killed. If we examine the cells at the ends of the threads of spirogyra we shall see in most cases that the cell wall at the free end is arched outward. This is brought about by the pressure from within upon the protoplasmic membrane which itself presses against the cell wall, and causes it to arch outward. This is beautifully shown in the case of threads which are recently broken. The cell wall is therefore *elastic;* it yields to a certain extent to the pressure from within, but a point is soon reached beyond which it will not stretch, and an equilibrium then exists between the pressure from within on the protoplasmic membrane, and the pressure from without by the elastic cell wall. This state of equilibrium in a cell is *turgescence,* or such a cell is said to be *turgescent,* or *turgid.*

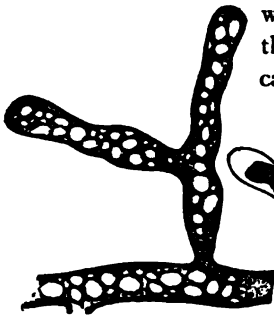

Fig. 14.
Before treatment with salt solution.

Fig. 15.
After treatment with salt solution.

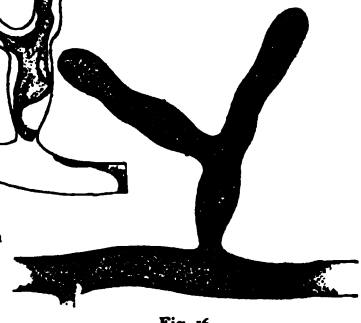

Fig. 16.
From salt solution placed in water.
Figs. 14–16.—Osmosis in threads of mucor.

32. Experiment with beet in salt and sugar solutions.—We may now test the effect of a five per cent salt solution on a portion of the tissues of a beet or carrot. Let us cut several slices of equal size and about 5*mm* in thickness. Immerse a few slices in water, a few in a five per cent salt solution and a few in a strong sugar solution. It should be first noted that all the slices are quite rigid when an attempt is made to bend them between the fingers. In the course of one or two hours or less,

if we examine the slices we shall find that those in water remain, as at first, quite rigid, while those in the salt and sugar solutions are more or less flaccid or limp, and readily bend by pres-

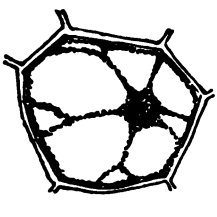

Fig. 17. Before treatment with salt solution.

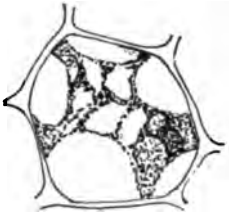

Fig. 18. After treatment with salt solution.

Fig. 19. From salt solution into water again.

Figs. 17–19.—Osmosis in cells of Indian corn.

sure between the fingers, the specimens in the salt solution, perhaps, being more flaccid than those in the sugar solution. The salt solution, we judge after our experiment with spirogyra,

Fig. 20. Rigid condition of fresh beet section.

Fig. 21. Limp condition after lying in salt solution.

Fig. 22. Rigid again after lying again in water.

Figs. 20–22.—Turgor and osmosis in slices of beet.

withdraws some of the water from the cell-sap, the cells thus losing their turgidity and the tissues becoming limp or flaccid from the loss of water.

33. Let us now remove some of the slices of the beet from the sugar and salt solutions, wash them with water and then immerse them in fresh water. In the course of thirty minutes to one hour, if we examine them again, we find that they have regained, partly or completely, their rigidity. Here again we infer from the former experiment with spirogyra that the substances in the cell-sap now draw water inward; that is, the diffusion current is inward through the cell walls and the protoplasmic membrane, and the tissue becomes turgid again.

34. Osmose in the cells of the beet.—We should now make a section of the fresh tissue of a red colored beet for examination with the microscope, and treat this section with the salt solution. Here we can see that the effect of the salt solution is to draw water out of the cell, so that the protoplasmic mem-

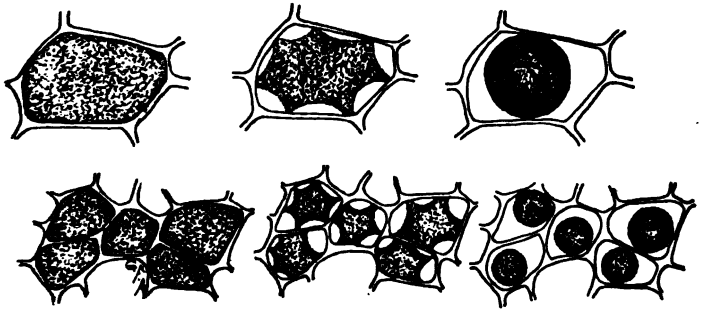

Fig. 23. Before treatment with salt solution.

Fig. 24. After treatment with salt solution.

Fig. 25. Later stage of the same.

Figs. 23–25.—Cells from beet treated with salt solution to show osmosis and movement of the protoplasmic membrane.

brane can be seen to move inward from the cell wall just as was observed in the case of spirogyra.* Now treating the section with water and removing the salt solution, the diffusion current is in the opposite direction, that is in-

* We should note that the coloring matter of the beet resides in the cell-sap. It is in these colored cells that we can best see the movement take place, since the red color serves to differentiate well the moving mass from the cell wall. The protoplasmic membrane at several points usually clings tenaciously so that at several places the membrane is arched strongly away from the cell wall as shown in fig. 24. While water is removed from the cell-sap, we note that the coloring matter does not escape through the protoplasmic membrane.

ward through the protoplasmic membrane, so that the latter is pressed outward until it comes in contact with the cell wall again, which by its elasticity soon resists the pressure and the cells again become turgid.

35. The coloring matter in the cell-sap does not readily escape from the living protoplasm of the beet.—The red coloring matter, as seen in the section under the microscope, does not escape from the cell-sap through the protoplasmic membrane. When the slices are placed in water, the water is not colored thereby. The same is true when the slices are placed in the salt or sugar solutions. Although water is withdrawn from the cell-sap, this coloring substance does not escape, or if it does it escapes slowly and after a considerable time.

36. The coloring matter escapes from dead protoplasm.—If, however, we heat the water containing a slice of beet up to a point which is sufficient to kill the protoplasm, the red coloring matter in the cell-sap filters out through the protoplasmic membrane and colors the water. If we heat a preparation made for study under the microscope up to the thermal death point we can see here that the red coloring matter escapes through the membrane into the water outside. This teaches that certain substances cannot readily filter through the living membrane of protoplasm, but that they can filter through when the protoplasm is dead. A very important condition, then, for the successful operation of some of the physical processes connected with absorption in plants is that the protoplasm should be in a living condition.

37. Osmose experiments with leaves.—We may next take the leaves of certain plants like the geranium, coleus or other plant, and place them in shallow vessels containing water, salt, and sugar solutions respectively. The leaves should be immersed, but the petioles should project out of the water or solutions. Seedlings of corn or beans, especially the latter, may also be placed in these solutions, so that the leafy ends are immersed. After one or two hours an examination shows that the specimens in the water are still turgid. But if we lift a leaf or a bean plant from the salt or sugar solution, we find that it is flaccid and limp. The blade, or lamina, of the leaf droops as if wilted, though it is still wet. The bean seedling also is flaccid, the succulent stem bending nearly double as the lower part of the stem is held upright. This loss of turgidity is brought about by the loss of water from the tissues, and judging from the experiments on spirogyra and the beet, we conclude that the loss of turgidity is caused by the withdrawal of some of the water from the cell-sap by the strong salt solution.

38. Now if we wash carefully these leaves and seedlings, which have been in the salt and sugar solutions, with water, and then immerse them in fresh water for a few hours, they will regain their turgidity. Here again we are led to infer that the diffusion current is now inward through the protoplasmic membranes of all the living cells of the leaf, and that the resulting turgidity of the individual cells causes the turgidity of the leaf or stem.

39. Absorption by root hairs.—If we examine seedlings, which have been grown in a germinator or in the folds of paper or cloths so that the roots will be free from particles of soil, we see near the growing point of the roots that the surface is covered with numerous slender, delicate, thread-like bodies, the root hairs. Let us place a portion of a small root containing some of these root hairs in water on a glass slip, and prepare it for examination with the microscope. We see that each thread, or root hair, is a continuous tube, or in other words it is a single cell which has become very much elongated. The protoplasmic membrane lines the wall, and strands of protoplasm extend across at irregular intervals, the interspaces being occupied by the cell-sap.

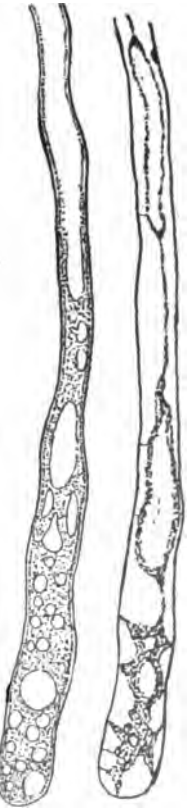

Fig. 27.
Root hair of corn before and after treatment with 5% salt solution.

We should now draw under the cover glass some of the five per cent salt solution. The protoplasmic membrane moves away from the cell wall at certain points, showing that *plasmolysis* is taking place, that is, the diffusion current is outward so that the cell-sap loses some of its water, and the pressure from the outside moves the membrane inward. We should not allow the salt solution to work on the root hairs long. It should be very soon removed by drawing in fresh water before the protoplasmic membrane has been broken at intervals, as is apt to be the case by the strong diffusion current and the consequent strong pressure from without. The membrane of protoplasm now moves outward as the diffusion current is inward, and soon regains its former position next the inner side of the cell wall. The root hairs then, like other parts of the plant which we have

Fig. 26.
Seedling of radish, showing root hairs.

investigated, have the power of taking up water under pressure.

40. Cell-sap a solution of certain substances —From these experiments we are led to believe that certain substances reside in the cell-sap of plants, which behave very much like the salt solution when separated from water by the protoplasmic membrane. Let us attempt to interpret these phenomena by recourse to diffusion experiments, where an animal membrane separates two liquids of different concentration.

41. An artificial cell to illustrate turgor.—Fill a small wide-mouthed vial with a *very strong* sugar solution. Over the mouth tie firmly a piece of *bladder* membrane. Be certain that as the membrane is tied over the open end of the vial, the sugar solution fills it in order to keep out air-

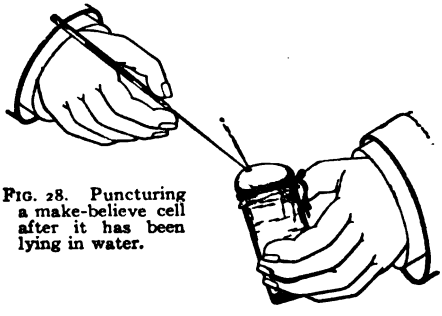

FIG. 28. Puncturing a make-believe cell after it has been lying in water.

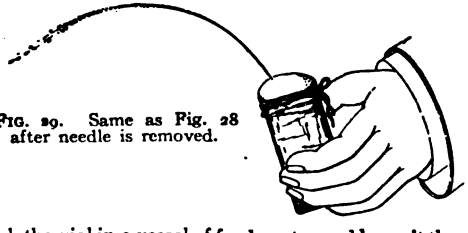

FIG. 29. Same as Fig. 28 after needle is removed.

bubbles. Sink the vial in a vessel of fresh water and leave it there for twenty-four hours. Remove the vial and note that the membrane is arched outward. Thrust a sharp needle through the membrane when it is arched outward, and quickly pull it out. The liquid spurts out because of the inside pressure.

42. Diffusion through an animal membrane.—For this experiment we may use a thistle tube, across the larger end of which should be stretched and tied tightly a piece of a bladder membrane. A strong sugar solution (three parts sugar to one part water) is now placed in the tube so that the bulb is

filled and the liquid extends part way in the neck of the tube. This is immersed in water within a wide-mouth bottle, the neck of the tube being supported in a perforated cork in such a way that the sugar solution in the tube is on a level with the water in the bottle or jar. In a short while the liquid begins to rise in the thistle tube, in the course of several hours having risen several centimeters. The diffusion current is thus stronger through the membrane in the direction of the sugar solution, so that this gains more water than it loses.

We have here two liquids separated by an animal membrane, water on the one hand which diffuses readily through the membrane, while on the other is a solution of sugar which diffuses through the animal membrane with difficulty. The water, therefore, not containing any solvent, according to a general law which has been found to obtain in such cases, diffuses more readily through the membrane into the sugar solution, which thus increases in volume, and also becomes more dilute. The bladder membrane is what is sometimes called a diffusion membrane, since the diffusion currents travel through it.

43. In this experiment then the bulk of the sugar solution is increased, and the liquid rises in the tube by this pressure above the level of the water in the jar outside of the thistle tube. The diffusion of liquids through a membrane is *osmosis*.

44. Importance of these physical processes in plants.—Now if we recur to our experiment with spirogyra we find that exactly the same processes take place. The protoplasmic membrane is the diffusion membrane, through which the diffusion takes place. The salt solution which is first used to bathe the threads of the plant is a stronger solution than that of the cell-sap within the cell. Water therefore is drawn out of the cell-sap, but the substances in solution in the cell-sap do not readily move out. As the bulk of the cell-sap diminishes the pressure from the outside pushes the protoplasmic membrane away from the wall. Now when we remove the salt solution and bathe the thread with water again, the cell-sap, being a solution of certain substances, diffuses with more difficulty than the water, and the diffusion current is inward, while the protoplasmic membrane moves out against the cell wall, and turgidity again results. Also in the experiments with salt and sugar solutions on the leaves of geranium, on the leaves and stems of the seedlings, on the tissues and cells of the beet and carrot, and on the root hairs of the seedlings, the same processes take place.

These experiments not only teach us that in the protoplasmic membrane, the cell wall, and the cell-sap of plants do we have structures which are capable of performing these physical processes, but they also show that these processes are of the utmost importance to the plant; not only in giving the plant the power to take up solutions of nutriment from the soil, but they serve also other purposes, as we shall see later.

CHAPTER III.

HOW PLANTS OBTAIN WATER.

In connection with the study of the means of absorption from the soil or water by plants, it will be found convenient to observe carefully the various forms of the plant. Without going into detail here, the suggestion is made that simple thread forms like spirogyra, œdogonium, and vaucheria; expanded masses of cells as are found in the thalloid liverworts, the duckweed, etc., be compared with those liverworts, and with the mosses, where leaf-like expansions of a central axis have been differentiated. We should then note how this differentiation, from the physiological standpoint, has been carried farther in the higher land plants.

45. Absorption by Algæ and Fungi.—In the simpler forms of plant life, as in spirogyra and many of the algæ and fungi, the plant body is not differentiated into parts.* In many other cases the only differentiation is between the growing part and the fruiting part. In the algæ and fungi there is no differentiation into stem and leaf, though there is an approach to it in some of the higher forms. Where this simple plant body is flattened, as in the sea-wrack, or ulva, it is a *frond*. The Latin word for frond is *thallus*, and this name is applied to the plant body of all the lower plants, the algæ and fungi. The algæ and fungi together are sometimes called the *thallophytes*, or *thallus plants*. The word thallus is also sometimes applied to the flattened body of the liverworts. In the foliose liverworts and mosses there is an axis with leaf-like expansions. These are believed by some to represent true stems and leaves, by others to represent a flattened thallus in which the margins are deeply and regularly divided, or in which the expansion has only taken place at regular intervals.

In nearly all of the algæ the plant body is submerged in water. In these

* See Chapter 38 for organization of members of the plant body.

cases absorption takes place through all portions of the surface in contact with the water, as in spirogyra, vaucheria, and all of the larger seaweeds. Comparatively few of the algæ grow on the surfaces of rocks or trees. In these examples it is likely that at times only portions of the plant body serve in the process of absorption of water from the substratum. A few of the algæ are parasitic, living in the tissues of higher plants, where they are surrounded by the water or liquids within the host. Absorption takes place in the same way in many of the fungi. The aquatic fungi are immersed in water. In other forms, like mucor, a portion of the mycelium is within the substratum, and being bathed by the water or watery solutions absorbs the same, while the fruiting portion and the aerial mycelium obtain their water and food solutions from the mycelium in the substratum. In higher fungi, like the mushrooms, the mycelium within the ground or decaying wood absorbs the water necessary for the fruiting portion; while in the case of the parasitic fungi the mycelium lies in the water or liquid within the host.

46. Absorption by liverworts.—In many of the plants termed liverworts the vegetative part of the plant is a thin, flattened, more or less elongated green body know as a thallus.

Riccia.—One of these, belonging to the genus riccia, is shown in fig. 30. Its shape is somewhat like that of a minute ribbon which is forked at intervals in a dichotomous manner, the characteristic kind of branching found in these thalloid liverworts. This riccia (known as R. lutescens) occurs on damp soil; long, slender, hair-like processes grow out from the under surface of the thallus which resemble root hairs and serve the same purpose in the processes of absorption. Another species of riccia (R. crystallina) is shown in fig. 252. This plant is quite circular in outline and occurs on muddy flats. Some species float on the water.

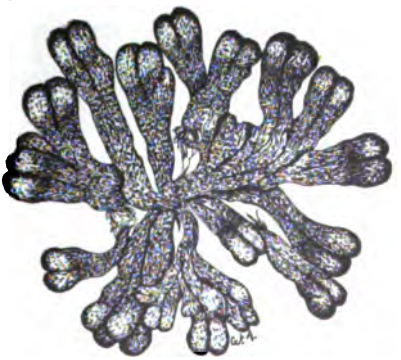

Fig. 30.
Thallus of Riccia lutescens.

47. Marchantia.—One of the larger and coarser liverworts is figured at 31. This is a very common liverwort, growing in very damp and muddy places and also along the margins of streams, on the mud or upon the surfaces of rocks which are

bathed with the water. This is known as *Marchantia polymorpha*. If we examine the under surface of the marchantia we see numerous hair-like processes which attach the plant to the soil. Under the microscope we see that some of these are similar to the root hairs of the seedlings which we have been studying, and they serve the purpose of absorption. Since, however, there are no roots on the marchantia plant, these hair-like

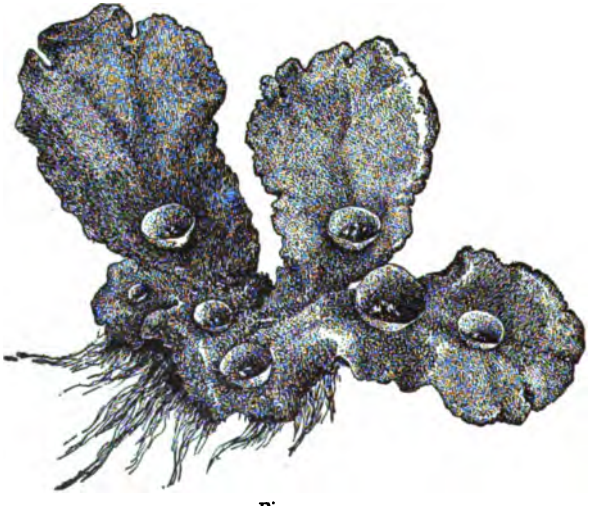

Fig. 31.
Marchantia plant with cupules and gemmæ; rhizoids below.

outgrowths are usually termed here *rhizoids*. In marchantia they are of two kinds, one kind the simple ones with smooth walls, and the other kind in which the inner surfaces of the walls are roughened by processes which extend inward in the form of irregular tooth-like points. Besides the hairs on the under side of the thallus we note especially near the growing end that there are two rows of leaf-like scales, those at the end of the thallus curving up over the growing end, thus serving to protect the delicate tissues at the growing point.

48. Frullania.—In fig. 32 is shown another liverwort, which differs greatly in form from the ones we have just been studying in that there is a well-defined axis with lateral leaf-like outgrowths. Such liverworts are called foliose liverworts. Besides these two quite prominent rows of leaves there is a third row of poorly developed leaves on the under surface. Also from the under surface of the axis we see here and there slender outgrowths, the rhizoids, through which much of the water is absorbed.

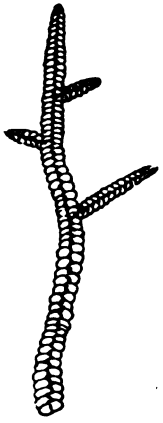

Fig. 32.
Portion of plant of Frullania, a foliose liverwort.

Fig. 33.
Portion of same more highly magnified, showing overlapping leaves.

Fig. 34.
Under side, showing forked under row of leaves and lobes of lateral leaves.

49. Absorption by the mosses.—Among the mosses, which are usually common in moist and shaded situations, examples are abundant which are suitable for the study of the organs of absorption. If we take for example a plant of mnium (M. affine), which is illustrated in fig. 36, we note that it consists of a slender

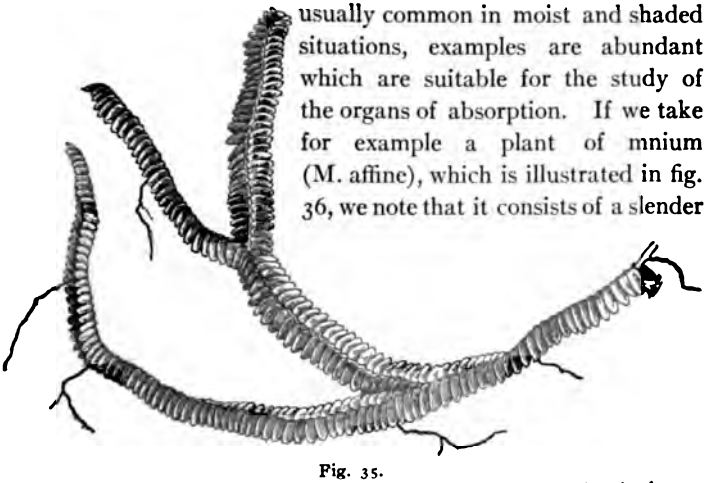

Fig. 35.
Foliose liverwort (bazzania) showing dichotomous branching and overlapping leaves.

axis with thin flat, green, leaf-like expansions. Examining with

the microscope the lower end of the axis, which is attached to the substratum, there are seen numerous brown-colored threads more or less branched.

50. Absorption by the higher aquatic plants.—Examples of the water plants which are entirely submerged in water are the water-crowfoots, some of the pond-weeds, elodea or water-weeds, the tape-grass, vallisneria, etc. In these plants all parts of the body being submerged, they absorb water with which they are in contact. In other aquatic plants, like the water-lilies, some of the pond-weeds, the duck-meats, etc., are only partially submerged in the water; the upper surface of the leaf or of the leaf-like expansion being exposed to the air, while the under surface lies in close contact with the water, and the stems and the petioles of the leaves are also immersed in water. In these plants absorption takes place through those parts in contact with the water.

Fig. 36.

Female plant (gametophyte) of a moss (mnium), showing rhizoids below, and the tuft of leaves above, which protect the archegonia.

51. Absorption by the duck-meats.—These plants are very curious examples of the higher plants.

Lemna.—One of these is illustrated in fig. 37. This is the common duckweed, *Lemna trisulca*. It is very peculiar in form and in its mode of growth. Each one of the lateral leaf-like expansions extends outwards by the elongation of the basal part, which becomes long and slender. Next, two new lateral expansions are formed on these by prolification from near the base, and thus the plant continues to extend. The plant occurs in ponds and ditches and is sometimes very common and abundant. It floats on the surface of the water. While the flattened part of the plant resembles a leaf, it is really the stem, no leaves being present. This expanded green body is usually termed a

"frond." A single rootlet grows out from the under side and is destitute

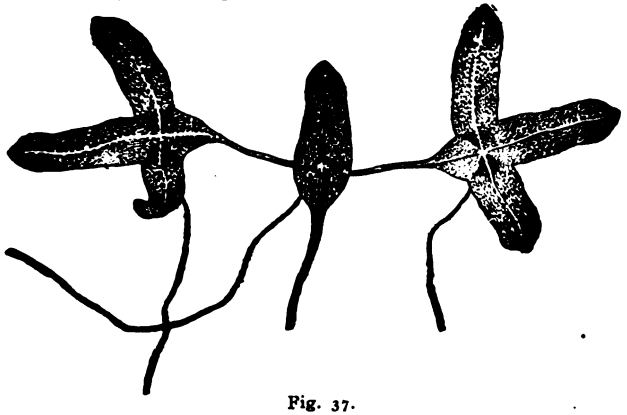

Fig. 37.
Fronds of the duckweed (Lemna trisculca).

of root hairs. Absorption of water therefore takes place through this rootlet and through the under side of the "frond."

52. Spirodela polyrhiza.—This is a very curious plant, closely related to the lemna and sometimes placed in the same genus. It occurs in similar situations, and is very readily grown in aquaria. It reminds one of a little insect as seen in fig. 38. There are several rootlets on the under side of the frond. Absorption of water takes place here in the same way as in lemna.

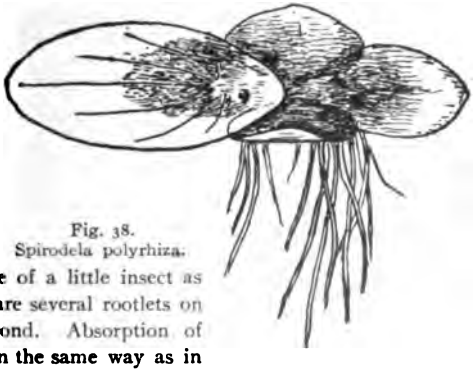

Fig. 38.
Spirodela polyrhiza.

53. Absorption in wolffia.—Perhaps the most curious of these modified water plants is the little wolffia, which contains the smallest specimens of the flowering plants. Two species of this genus are shown in figs. 39–41. The plant body is reduced to nothing but a rounded or oval green body, which represents the stem. No leaves or roots are present. The plants multiply by "prolification," the new fronds growing out from a depression on the under side of one end. Absorption takes place through the surface in contact with the water.

54. Absorption by land plants.—*Water cultures.*—In connection with our inquiry as to how land plants obtain their water, it

will be convenient to prepare some water cultures to illustrate this and which can also be used later in our study of nutrition (Chapter IX).

Fig. 39.
Young frond of wolffia growing out of older one.

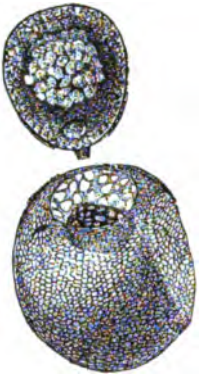

Fig. 40.
Young frond of wolffia separating from older one.

Fig. 41.
Another species of wolffia, the two fronds still connected.

Chemical analysis shows that certain mineral substances are common constituents of plants. By growing plants in different solutions of these various substances it has been possible to determine what ones are necessary constituents of plant food. While the proportion of the mineral elements which enter into the composition of plant food may vary considerably within certain limits, the concentration of the solutions should not exceed certain limits. A very useful solution is one recommended by Sachs, and is as follows:

55. Formula for water cultures:

Water	1000 cc.
Potassium nitrate	0.5 gr.
Sodium chloride	0.5 "
Calcium sulphate	0.5 "
Magnesium sulphate	0.5 "
Calcium phosphate	0.5 "

The calcium phosphate is only partly soluble. The solution which is not in use should be kept in a dark cool place to prevent the growth of minute algæ.

56. Several different plants are useful for experiments in water cultures, as peas, corn, beans, buckwheat, etc. The seeds of these plants may be germinated, after soaking them for several hours in warm water, by placing

them between the folds of wet paper on shallow trays, or in the folds of wet cloth. The seeds should not be kept immersed in water after they have imbibed enough to thoroughly soak and swell them. At the same time that the seeds are placed in damp paper or cloth for germination, one lot of the soaked seeds should be planted in good soil and kept under the same temperature conditions, for control. When the plants have germinated one series should be grown in distilled water, which possesses no plant food; another in the nutrient solution, and still another in the nutrient solution to which has been added a few drops of a solution of iron chloride or ferrous sulphate. There would then be four series of cultures which should be carried out with the same kind of seed in each series so that the comparisons can be made on the same species under the different conditions. The series should be numbered and recorded as follows:

No. 1, soil.

No. 2, distilled water.

No. 3, nutrient solution.

No. 4, nutrient solution with a few drops of iron solution added.

57. Small jars or wide-mouth bottles, or crockery jars, can be used for the water cultures, and the cultures are set up as follows: A cork which will just fit in the mouth of the bottle, or which can be supported by pins, is perforated so that there is room to insert the seedling, with the root projecting below into the liquid. The seed can be fastened in position by inserting a pin through one side, if it is a large one, or in the case of small seeds a cloth of a coarse mesh can be tied over the mouth of the bottle instead of using the cork. After properly setting up the experiments the cultures should be arranged in a suitable place, and observed from time to time during several weeks. In order to obtain more satisfactory results several duplicate series should be set up to guard against the error which might arise from variation in individual plants and from accident Where there are several students in a class, a single series set up by several will act as checks upon one another. If glass jars are used for the liquid cultures they should be wrapped with black paper or cloth to exclude the light from the liquid, otherwise numerous minute algæ are apt to grow and interfere with the experiment. Or the jars may be sunk in pots of earth to serve the same purpose. If crockery jars are used they will not need covering.

Fig. 42.
Culture cylinder to show position of corn seedling (Hansen).

58. For some time all the plants grow equally well, until the nutriment stored in the seed is exhausted. The numbers 1, 3 and 4, in soil and nutri-

ent solutions, should outstrip number 2, the plants in the distilled water. No. 4 in the nutrient solution with iron, having a perfect food, compares favorably with the plants in the soil.

59. Plants take liquid food from the soil.—From these experiments then we judge that such plants take up the food they receive from the soil in the form of a liquid, the elements being in solution in water.

If we recur now to the experiments which were performed with the salt solution in producing plasmolysis in the cells of spirogyra, in the cells of the beet or corn, and in the root hairs of the corn and bean seedlings, and the way in which these cells become turgid again when the salt solution is removed and they are again bathed with water, we shall have an explanation of the way in which plants take up nutrient solutions of food material through their roots.

60. How food solutions are carried into the plant.—We can

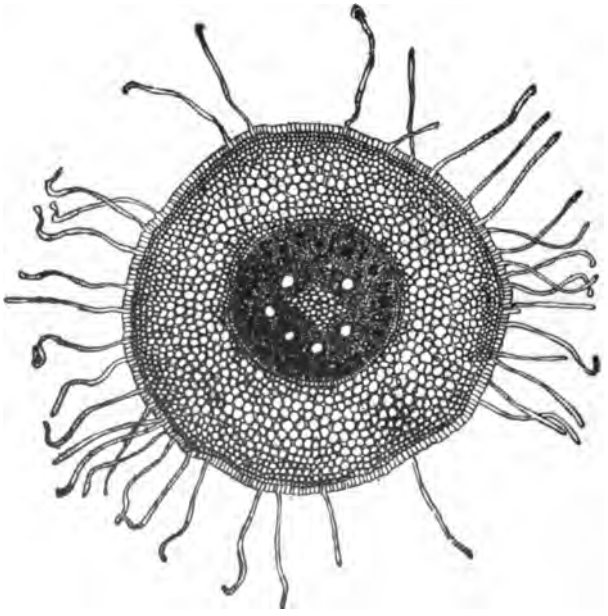

Fig. 43.
Section of corn root, showing root hairs formed from elongated epidermal cells.

and we must next turn our attention to the way in which these solutions are carried farther into the plant. We should make a section across the root of a seedling in the region of the root hairs and examine it with the aid of a microscope. We here see that the root hairs are formed by the elongation of certain of the surface cells of the root. These cells elongate perpendicularly to the root, and become 3*mm* to 6*mm* long. They are flexuous or irregular in outline and cylindrical, as shown in fig. 43. The end of the hair next the root fits in between the adjacent superficial cells of the root and joins closely to the next deeper layer of cells. In studying the section of the young root we see that the root is made up of cells which lie closely side by side, each with its wall, its protoplasm and cell-sap, the protoplasmic membrane lying on the inside of each cell wall.

61. In the absorption of the watery solutions of plant food by the root hairs, the cell-sap, being a more concentrated solution, gains some of the former, since the liquid of less concentration flows through the protoplasmic membrane into the more concentrated cell-sap, increasing the bulk of the latter. This makes the root hairs turgid, and at the same time dilutes the cell-sap so that the concentration is not so great. The cells of the root lying inside and close to the base of the root hairs have a cell-sap which is now more concentrated than the diluted cell-sap of the hairs, and consequently gain some of the food solutions from the latter, which tends to lessen the content of the root hairs and also to increase the concentration of the cell-sap of the same. This makes it possible for the root hairs to draw on the soil for more of the food solutions, and thus, by a variation in the concentration of the substances in solution in the cell-sap of the different cells, the food solutions are carried along until they reach the *vascular bundles*, through which the solutions are carried to distant parts of the plant. Some believe that there is a rhythmic action of the elastic cell walls in these cells between the root hairs and the vascular bundles. This occurs in such a way that, after the cell becomes turgid, it contracts, thus reducing the size of the cell and forcing some of the food solutions into the adjacent cells, when by absorption of more food solutions, or water, the cell increases in turgidity again. This rhythmic action of the cells, if it does take place, would act as a pump to force the solutions along, and would form one of the causes of root pressure.

62. How the root hairs get the watery solutions from the soil.—If we examine the root hairs of a number of seedlings which are growing in the soil under normal conditions, we shall see that a large quantity of soil readily clings to the roots. We should note also that unless the soil has been recently watered there is no free water in it; the soil is only moist. We are curious

to know how plants can obtain water from soil which is not wet. If we attempt to wash off the soil from the roots, being careful not to break away the

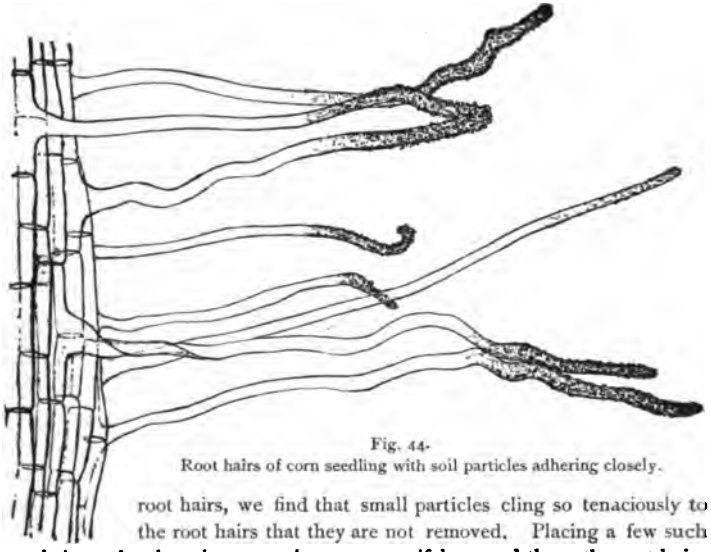

Fig. 44.
Root hairs of corn seedling with soil particles adhering closely.

root hairs, we find that small particles cling so tenaciously to the root hairs that they are not removed. Placing a few such root hairs under the microscope it appears as if here and there the root hairs were glued to the minute soil particles.

63. If now we take some of the soil which is only moist, weigh it, and then permit it to become quite dry on exposure to dry air, and weigh again, we find that it loses weight in drying. Moisture has been given off. This moisture, it has been found, forms an exceedingly thin film on the surface of the minute soil particles. Where these soil particles lie closely together, as they usually do when massed together in the pot or elsewhere, this thin film of moisture is continuous from the surface of one particle to that of another. Thus the soil particles which are so closely attached to the root hairs connect the surface of the root hairs with this film of moisture. As the cell-sap of the root hairs draws on the moisture film with which they are in contact, the tension of this film is sufficient to draw moisture from distant particles. In this way the roots are supplied with water in soil which is only moist.

64. Plants cannot remove all the moisture from the soil.—If we now take a potted plant, or a pot containing a number of seedlings, place it in a moderately dry room, and do not add water to the soil we find in a few days that the plant is wilting. The soil if examined will appear quite dry to the sense of touch. Let us weigh some of this soil, then dry it by artificial

heat, and weigh again. It has lost in weight. This has been brought about by driving off the moisture which still remained in the soil after the plant began to wilt. This teaches that while plants can obtain water from soil which is only moist or which is even rather dry, they are not able to withdraw all the moisture from the soil.

65. "Root pressure" or exudation pressure.—It is a very common thing to note, when certain shrubs or vines are pruned in the spring, the exudation of a watery fluid from the cut surfaces. In the case of the grape vine this has been known to continue for a number of days, and in some cases the amount of liquid, called "sap," which escapes is considerable. In many cases it is directly traceable to the activity of the roots, or root hairs, in the absorption of water from the soil. For this reason the term *root pressure* has been used to denote the force exerted in supplying the water from the soil. But there are some who object to the use of this term "root pressure." The principal objection is that the pressure which brings about the phenomenon known as "bleeding" by plants is not present in the roots alone. This pressure exists under certain conditions in all parts of the plant. The term exudation pressure has been proposed in lieu of root pressure. It should be remembered that the movement of water in the plant is started by the pressure which exists in the root. If the term "root pressure" is used, it should be borne clearly in mind that it does not express the phenomenon exactly in all cases.

Root pressure may be measured.—It is possible to measure not only the amount of water which the roots will raise in a given time, but also to measure the force exerted by the roots during root pressure. It has been found that root pressure in the case of the nettle is sufficient to hold a column of water about 4.5 meters (15 ft.) high (Vines), while the root pressure of the vine (Hales, 1721) will hold a column of water about 10 meters (36.5 ft.) high, and the birch (Betula lutea) (Clark, 1873) has a root pressure sufficient to hold a column of water about 25 meters (84.7 ft.) high.

66. Experiment to demonstrate root pressure.—By a very simple method this lifting of water by root pressure is shown. During the summer season

plants in the open may be used if it is preferred, but plants grown in pots are also very serviceable, and one may use a potted begonia or balsam, the latter being especially useful. The plants are usually convenient to obtain from the greenhouses, to illustrate this phenomenon. The stem is cut off rather close to the soil and a long glass tube is attached to the cut end of the stem, still connected with the roots, by the use of rubber tubing, as shown in figure 45, and a very small quantity of water may be poured in to moisten the cut end of the stem. In a few minutes the water begins to rise in the glass tube. In some cases it rises quite rapidly, so that the column of water can readily be seen to extend higher and higher up in the tube when observed at quite short intervals. (To measure the force of root pressure is rather difficult for elementary work. To measure it see Ganong, Plant Physiology, pp. 67, 68, or some other book for advanced work.)

Fig. 45. Experiment to show root pressure (Detmer).

67. In either case where the experiment is continued for several days it is noticed that the column of water or of mercury rises and falls at different times during the same day, that is, the column stands at varying heights; or in other words the root presssure varies during the day. With some plants it has been found that the pressure is greatest at certain times of the day, or at certain seasons of the year. Such variation of root pressure exhibits what is termed a periodicity, and in the case of some plants there is a daily periodicity; while in others there is in addition an annual periodicity. With the grape vine the root pressure is greatest in the forenoon, and decreases from 12–6 P.M., while with the sunflower it is greatest before 10 A.M., when it begins to decrease. Temperature of the soil is one of the most important external conditions affecting the activity of root pressure.

CHAPTER IV.

TRANSPIRATION, OR THE LOSS OF WATER BY PLANTS.

68. We should now inquire if all the water which is taken up in excess of that which actually suffices for turgidity is used in the elaboration of new materials of construction. We notice when a leaf or shoot is cut away from a plant, unless it is kept in quite a moist condition, or in a damp, cool place, that it becomes flaccid, and droops. It wilts, as we say. The leaves and shoot lose their turgidity. This fact suggests that there has been a loss of water from the shoot or leaf. It can be readily seen that this loss is not in the form of drops of water which issue from the cut end of the shoot or petiole. What then becomes of the water in the cut leaf or shoot?

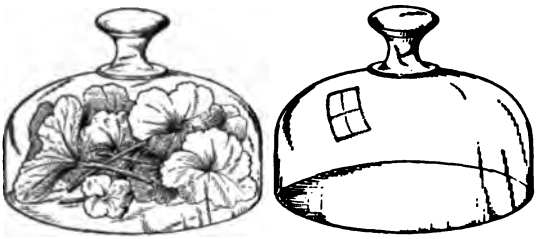

Fig. 46.
To show loss of water from leaves, the leaves just covered.

69. Loss of water from excised leaves.—Let us take a handful of fresh, green, rather succulent leaves, which are free from

water on the surface, and place them under a glass bell jar, which is tightly closed below but which contains no water. Now place this in a brightly lighted window, or in sunlight. In the course of fifteen to thirty minutes we notice that a thin film of moisture is accumulating on the inner surface of the glass jar. After an hour or more the moisture has accumulated so that it appears in the form of small drops of condensed water. We should set up at the same time a bell jar in exactly the same way but which contains no leaves. In this jar there is no condensed moisture on the inner surface. We thus are justified in concluding that

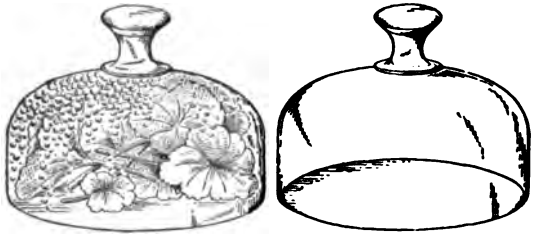

Fig. 47.
After a few hours drops of water have accumulated on the inside of the jar covering the leaves.

the moisture in the former jar comes from the leaves. Since there is no visible water on the surfaces of the leaves, or at the cut ends, before it may have condensed there, we infer that the water escapes from the leaves in the form of *water vapor*, and that this water vapor, when it comes in contact with the surface of the cold glass, condenses and forms the moisture film, and later the drops of water. The leaves of these cut shoots therefore lose water in the form of water vapor, and thus a loss of turgidity results.

70. Loss of water from growing plants.—Suppose we now take a small and actively growing plant in a pot, and cover the pot and the soil with a sheet of rubber cloth or flexible oilcloth

which fits tightly around the stem of the plant so that the moisture from the soil or from the surface of the pot cannot escape. Then place a bell jar over the plant, and set in a brightly lighted place, at a temperature suitable for growth. In the course of a few minutes on a dry day a moisture film forms on the inner surface of the glass, just as it did in the case of the glass jar containing the cut shoots and leaves. Later the moisture has condensed so that it is in the form of drops. If we have the same leaf surface here as we had with the cut shoots, we shall probably find that a larger amount of water accumulates on the surface of the jar from the plant that is still attached to its roots.

71. Water escapes from the surfaces of living leaves in the form of water vapor.—This living plant then has lost water, which also escapes in the form of water vapor. Since here there are no cut places on the shoots or leaves, we infer that the loss of water vapor takes place from the surfaces of the leaves and from the shoots. It is also to be noted that, while this plant is losing water from the surfaces of the leaves, it does not wilt or lose its turgidity. The roots by their activity and pressure supply water to take the place of that which is given off in the form of water vapor. This loss of water in the form of water vapor by plants is *transpiration.*

72. A test for the escape of water vapor from plants.—Make a solution of cobalt chloride in water. Saturate several pieces of filter paper with it. Allow them to dry. The water solution of cobalt chloride is red. The paper is also red when it is moist, but when it is thoroughly dry it is blue. It is very sensitive to moisture and the moisture of the air is often sufficient to redden it. Before using dry the paper in an oven or over a flame.

73. Take two bell jars, as shown in fig. 49. Under one place a potted plant, the pot and earth being covered by oiled paper. Or cover the plant with a fruit jar. To a stake in the pot pin a piece of the dried cobalt paper, and at the same time pin to a

stake, in another jar covering no plant, another piece of cobalt paper. They should both be put under the jars at the same time. In a few moments the paper in the jar with the plant will begin to redden. In a short while, ten or fifteen minutes, probably, it will be entirely red, while the paper under the other jar will remain blue, or be only slightly reddened. The water vapor passing off from the living plant comes in contact with the sensi-

Fig. 48.

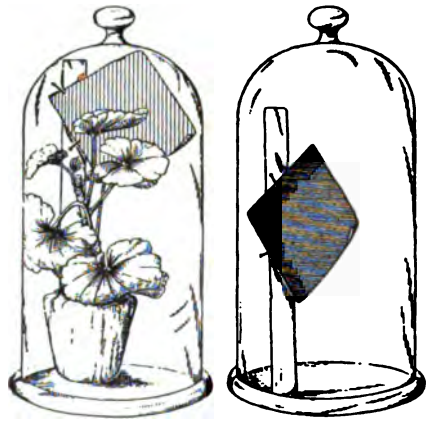

Fig. 49.

Fig. 48.—Water vapor is given off by the leaves when attached to the living plant. It condenses into drops of water on the cool surface of the glass covering the plant.
Fig. 49.—A good way to show that the water passes off from the leaves in the form of water vapor.

tive cobalt chloride in the paper and reddens it before there is sufficient vapor present to condense as a film of moisture on the surface of the jar.

74. Experiment to compare loss of water in a dry and a humid atmosphere.—We should now compare the escape of water from the leaves of a plant covered by a bell jar, as in the last experiment, with that which takes place when the plant is

exposed in a normal way in the air of the room or in the open. To do this we should select two plants of the same kind growing in pots, and of approximately the same leaf surface. The potted plants are placed one each on the arms of a scale. One of the plants is covered in this position with a bell jar. With weights placed on the pan of the other arm the two sides are balanced. In the course of an hour, if the air of the room is dry, moisture has probably accumulated on the inner surface of the glass jar which is used to cover one of the plants. This indicates that there has here been a loss of water. But there is no escape of water vapor into the surrounding air so that the weight on this arm is practically the same as at the beginning of the experiment. We see, however, that the other arm of the balance has risen. We infer that this is the result of the loss of water vapor from the plant on that arm. Now let us remove the bell jar from the other plant, and with a cloth wipe off all the moisture from the inner surface, and replace the jar over the plant. We note that the end of the scale which holds this plant is still lower than the other end.

75. The loss of water is greater in a dry than in a humid atmosphere.—This teaches us that while water vapor escaped from the plant under the bell jar, the air in this receiver soon became saturated with the moisture, and thus the farther escape of moisture from the leaves was checked. It also teaches us another very important fact, viz., that plants lose water more rapidly through their leaves in a dry air than in a humid or moist atmosphere. We can now understand why it is that during the very hot and dry part of certain days plants often wilt, while at nightfall, when the atmosphere is more humid, they revive. They lose more water through their leaves during the dry part of the day, other things being equal, than at other times.

76. How transpiration takes place.—Since the water of transpiration passes off in the form of water vapor we are led to inquire if this process is simply *evaporation* of water through the surface of the leaves, or whether it is controlled to any appreciable extent by any condition of the living plant. An experiment

which is instructive in this respect we shall find in a comparison between the transpiration of water from the leaves of a cut shoot, allowed to lie unprotected in a dry room, and a similar cut shoot the leaves of which have been killed.

77. Almost any plant will answer for the experiment. For this purpose I have used the following method. Small branches of the locust (Robinia pseudacacia), of sweet clover (Melilotus alba), and of a heliopsis were selected. One set of the shoots was immersed for a moment in hot water near the boiling point to kill them. The other set was immersed for the same length of time in cold water, so that the surfaces of the leaves might be well wetted, and thus the two sets of leaves at the beginning of the experiment would be similar, so far as the amount of water on their surfaces is concerned. All the shoots were then spread out on a table in a dry room, the leaves of the killed shoots being separated where they are inclined to cling together. In a short while all the water has evaporated from the surface of the living leaves, while the leaves of the dead shoots are still wet on the surface. In six hours the leaves of the dead shoots from which the surface water had now evaporated were beginning to dry up, while the leaves of the living plants were only becoming flaccid. In twenty-four hours the leaves of the dead shoots were crisp and brittle, while those of the living shoots were only wilted. In twenty-four hours more the leaves of the sweet clover and of the heliopsis were still soft and flexible, showing that they still contained more water than the killed shoots which had been crisp for more than a day.

78. It must be then that during what is termed transpiration the living plant is capable of holding back the water to some extent, which in a dead plant would escape more rapidly by evaporation. It is also known that a body of water with a surface equal to that of a given leaf surface of a plant loses more water by evaporation during the same length of time than the plant loses by transpiration.

79. Structure of a leaf.—We are now led to inquire why it is that a living leaf loses water less rapidly than dead ones, and why less water escapes from a given leaf surface than from an equal surface of water. To understand this it will be necessary to examine the minute structure of a leaf. For this purpose we may select the leaf of an ivy, though many other leaves will answer equally well. From a portion of the leaf we should make very thin cross sections with a razor or other sharp instrument. These sections should be perpendicular to the surface of the leaf

and should be then mounted in water for microscopic examination.*

80. Epidermis of the leaf.—In this section we see that the green part of the leaf is bordered on what are its upper and lower surfaces by a row of cells which possess no green color. The walls of the cells of each row have nearly parallel sides, and the cross walls are perpendicular. These cells form a single layer over both surfaces of the leaf and are termed the *epidermis*. Their walls are quite stout and the outer walls are *cuticularized*.

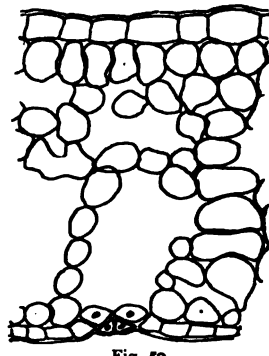

Fig. 50.
Section through ivy leaf showing communication between stomate and the large intercellular spaces of the leaf; stoma closed.

81. Soft tissue of the leaf.—The cells which contain the green chlorophyll bodies are arranged in two different ways. Those on the upper side of the leaf are usually long and prismatic in form and lie closely parallel to each other. Because of this arrangement of these cells they are termed the *palisade* cells, and form what is called the *palisade layer*. The other green cells, lying below, vary greatly in size in different plants and to some extent also in the same plant. Here we notice that they are elongated, or oval, or somewhat irregular in form. The most striking peculiarity, however, in their arrangement is that they are not usually packed closely together, but each cell touches the other adjacent cells only at certain points. This arrangement of these cells forms quite large spaces between them, the intercellular spaces. If we should examine such a section of a leaf before it is mounted in water we would see that the inter-

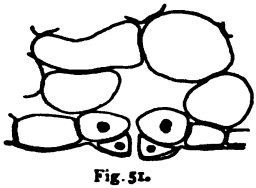

Fig. 51.
Stoma open.

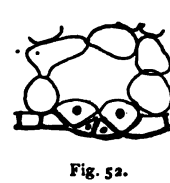

Fig. 52.
Stoma closed.

Figs. 34, 35.—Section through stomata of ivy leaf.

* Demonstrations may be made with prepared sections of leaves.

cellular spaces are not filled with water or cell-sap, but are filled with air or some gas. Within the cells, on the other hand, we find the cell-sap and the protoplasm.

82. Stomata.—If we examine carefully the row of epidermal cells on the under surface of the leaf, we find here and there a peculiar arrangement of cells shown at figs. 51, 52. This opening through the epidermal layer is a *stoma*. The cells which immediately surround the openings are the *guard cells*. The form of the guard cells can be better seen if we tear a leaf in such a way as to strip off a short piece of the lower epidermis, and mount this in water. The guard cells are nearly crescent shaped, and the stoma is elliptical in outline. The epidermal cells are very irregular in outline in this view. We should also note that while the epidermal cells contain no chlorophyll, the guard cells do.

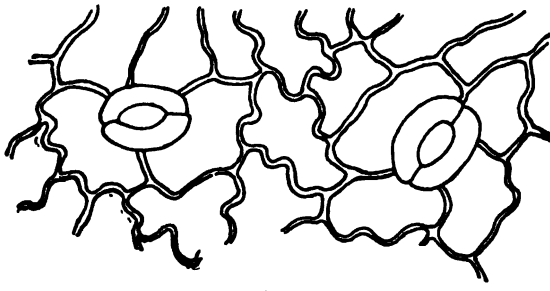

Fig. 53.
Portion of epidermis of ivy, showing irregular epidermal cells, stoma and guard cells.

82*a*. In the ivy leaf the guard cells are quite plain, but in most plants the form as seen in cross-section is irregular in outline, as shown in fig. 53*a*, which is from a section of a wintergreen leaf. This leaf is interesting because it shows the characteristic structure of leaves of many plants growing in soil where absorption of water by the roots is difficult owing to the cold water, acids, or salts in the water or soil, or in dry soil (see Chapters 47, 54, 55). The cuticle over the upper epidermis is quite thick. This lessens the loss of water by the leaf. The compact palisades of cells are in two to three cell layers, also reducing the loss of water.

83. The living protoplasm retards the evaporation of water from the leaf.—If we now take into consideration a few facts which we have learned

in a previous chapter, with reference to the physical properties of the living cell, we shall be able to give a partial explanation of the comparative slowness with which the water escapes from the leaves. The inner surfaces of the cell walls are lined with the membrane of protoplasm, and within this is the cell-sap. These cells have become turgid by the absorption of the

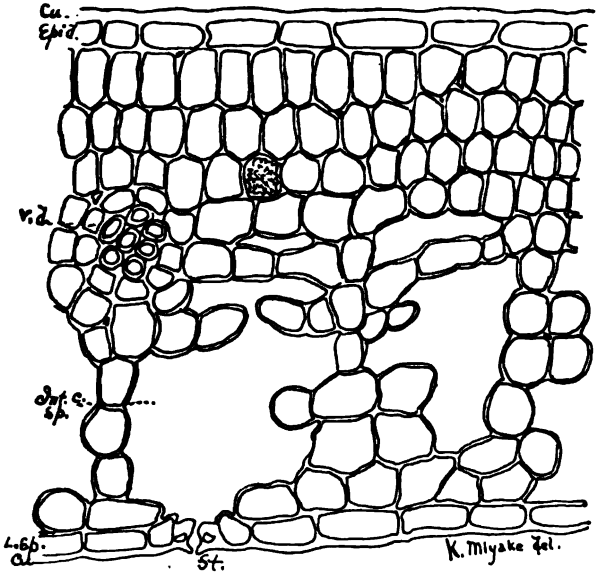

Fig. 53*a*.

Cross-section of leaf of wintergreen. *Cu.* cuticle; *Epid.*, epidermis; *v.d.*, vascular duct; *Int. c. sp.*, intercellular space; *L. ep.*, lower epidermis; *St.*, stoma.

water which has passed up to them from the roots. While the protoplasmic membrane of the cells does not readily permit the water to filter through, yet it is saturated with water, and the elastic cell wall with which it is in contact is also saturated. From the cell wall the water evaporates into the intercellular spaces. But the water is given up slowly through the protoplasmic membrane, so that the water vapor cannot be given off as rapidly from the cell walls as it could if the protoplasm were dead. The living protoplasmic membrane then which is only slowly permeable to the water of the cell-sap is here a very important factor in checking the too rapid loss of water from the leaves.

By an examination of our leaf section we see that the intercellular spaces are all connected, and that the stomata, where they occur, open also into intercellular spaces. There is here an opportunity for the water vapor in the intercellular spaces to escape when the stomata are open.

84. Action of the stomata.—The guard cells serve an important function in regulating transpiration. During normal transpiration the guard cells are turgid and their peculiar form then causes them to arch away from each other, allowing the escape of water vapor. When the air becomes too dry transpiration is in excess of absorption by the roots. The guard cells lose some of their water, and collapse so that their inner faces meet in a straight line and close the stoma. Thus the rapid transpiration is checked. Some evaporation of water vapor, however, takes place through the epidermal cells, and if the air remains too dry, the leaves eventually become flaccid and droop. During the day the effect of sunlight is to increase certain sugars or salts in the guard cells so that they readily become turgid and open the stomates, but at night the cell-sap is less concentrated and the stomates are usually closed. Light therefore favors transpiration, while in darkness transpiration is checked.

85. Compare transpiration from the two surfaces of the leaf.—This can be done by using the cobalt chloride paper. This paper can be kept from year to year and used repeatedly. It is thus a very simple matter to make these experiments. Provide two pieces of glass (discarded glass negatives, cleaned, are excellent), two pieces of cobalt chloride paper, and some geranium leaves entirely free from surface water. Dry the paper until it is blue. Place one piece of the paper on a glass plate; place the geranium leaf with the under side on the paper. On the upper side of the leaf now place the other cobalt paper, and next the second piece of glass. On the pile place a light weight to keep the parts well in contact. In fifteen or twenty minutes open and examine. The paper next the under side of the geranium leaf is red where it lies under the leaf. The paper on the upper side is only slightly reddened. The greater loss of water, then, is through the under side of the geranium leaf. This is true of a great many leaves, but it is not true of all.

86. Negative pressure.—This is not only indicated by the drooping of the leaves, but may be determined in another way. If the shoot of such a plant be cut underneath mercury, or underneath a strong solution of eosin, it will be found that some of the mercury or eosin, as the case may be, will be forcibly drawn up into the stem toward the roots. This is seen on quickly splitting the cut end of the stem. When plants in the open cannot be obtained in this condition, one may take a plant like a balsam plant from the greenhouse, or some other potted plant, knock it out of the pot, free the roots from the soil and allow to partly wilt. The stem may then be held under the eosin solution and cut.

87. Lifting power of transpiration.—Not only does transpiration go on quite independently of root pressure, as we have discovered from other experiments, but transpiration is capable of exerting a lifting power on the water in the plant. This may be demonstrated in the following way: Place the cut end of a leafy shoot in one end of a U tube and fit it water-tight. Partly fill this arm of the U tube with water, and add mercury to the other arm until it stands at a level in the two arms as in fig. 54. In a short time we note that the mercury is rising in the tube.

Fig. 54.
Experiment to show lifting power of transpiration.

88. Root pressure may exceed transpiration.—If we cover small actively growing plants, such as the pea, corn, wheat, bean, etc., with a bell jar, and place them in the sunlight where the temperature is suitable for growth, in a few hours, if conditions are favorable, we shall see that there are drops of water standing out on the margins of the leaves. These drops of water have exuded through the ordinary stomata, or in other cases what are called water stomata, through the influence of root pressure. The plant being covered by the glass jar, the air soon becomes saturated with moisture and transpiration is checked. Root pressure still goes on, however, and the result is shown in the exuding drops. Root pressure is here in excess of transpiration. This phenomenon is often to be observed during the summer season in the case of low-growing plants. During the bright warm day transpiration equals, or may be in excess of, root pressure, and the leaves are consequently flaccid. As nightfall comes on the air becomes more moist, and the conditions of light are such also that transpiration is lessened. Root pressure, however, is still active because the soil is still warm. In these cases drops of water may be seen exuding from the margins of the leaves due to the excess of root pressure over transpiration. Were it not for this provision for the escape of the excess of water raised by root pressure, serious injury by lesions, as a result of the great pressure, might result. The plant is thus to some extent a self-regulatory piece of apparatus so far as root pressure and transpiration are concerned.

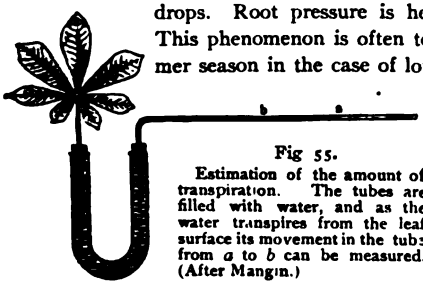

Fig 55.
Estimation of the amount of transpiration. The tubes are filled with water, and as the water transpires from the leaf surface its movement in the tube from *a* to *b* can be measured. (After Mangin.)

89. Injuries caused by excessive root pressure.—Some varieties of tomatoes when grown in poorly lighted and poorly ventilated greenhouses suffer

serious injury through lesions of the tissues. This is brought about by the cells at certain parts becoming charged so full with water through the activity of root pressure and lessened transpiration, assisted also probably by an accumulation of certain acids in the cell-sap which cannot be got rid of by transpiration. Under these conditions some of the cells here swell out, forming extensive cushions, and the cell walls become so weakened that they burst. It is possible to imitate the excess of root pressure in the case of some plants by connecting the stems with a system of water pressure, when very quickly the drops of water will begin to exude from the margins of the leaves.

Fig. 56.

The roots are lifting more water into the plant than can be given off in the form of water vapor, so it is pressed out in drops. From "First Studies Plant Life."

90. It should be stated that in reality there is no difference between transpiration and evaporation, if we bear in mind that evaporation takes place more slowly from living plants than from dead ones, or from an equal surface of water.

91. The escape of water vapor is not the only function of the stomata. The exchange of gases takes place through them as we shall later see. A large number of experiments show that normally the stomata are open when the leaves are turgid. But when plants lose excessive quantities of water on dry and hot days, so that the leaves become flaccid, the guard cells automatically close the stomata to check the escape of water vapor. Some water escapes through the epidermis of many plants, though the cuticularized membrane of the epidermis largely prevents evaporation. In arid regions plants are usually provided with an epidermis of several layers of cells to more securely prevent evaporation there. In such cases the guard cells are often protected by being sunk deeply in the epidermal layer.

92. Demonstration of stomates and intercellular air spaces.—A good demonstration of the presence of stomates in leaves, as well as the presence and intercommunication of the intercellular spaces, can be made by blowing into the cut end of the petiole of the leaf of a calla lily, the lamina being

immersed in water. The air is forced out through the stomata and rises as bubbles to the surface of the water. At the close of the experiment some of the air bubbles will still be in contact with the leaf surface at the opening of the stomata. The pressure of the water gradually forces this back into the leaf. Other plants will answer for the experiment, but some are more suitable than others.

93a. Number of stomata.—The larger number of stomata are on the under side of the leaf. (In leaves which float on the surface of the water all of the stomata are on the upper side of the leaf, as in the water lily.) It has been estimated by investigation that in general there are 40–300 stomata to the square millimeter of surface. In some plants this number is exceeded, as in the olive, where there are 625. In an entire leaf of Brassica rapa there are about 11,000,000 stomata, and in an entire leaf of the sunflower there are about 13,000,000 stomata.

93b. Amount of water transpired by plants.—The amount of water transpired by plants is very great. According to careful estimates a sunflower 6 feet high transpires on the average about one quart per day; an acre of cabbages 2,000,000 quarts in four months; an oak tree with 700,000 leaves transpires about 180 gallons of water per day. According to von Höhnel, a beech tree 110 years old transpired about 2250 gallons of water in one summer. A hectare of such trees (about 400 on 2¼ acres) would at the same rate transpire about 900,000 gallons, or about 30,000 barrels in one summer.

CHAPTER V.

PATH OF MOVEMENT OF WATER IN PLANTS.

93. In our study of root pressure and transpiration we have seen that large quantities of water or solutions move upward through the stems of plants. We are now led to inquire through what part of the stems the liquid passes in this upward movement, or in other words, what is the path of the "sap" as it rises in the stem. This we can readily see by the following trial.

94. Place the cut ends of leafy shoots in a solution of some of the red dyes.—We may cut off leafy shoots of various plants and insert the cut ends in a vessel of water to which have been added a few crystals of the dye known as fuchsin to make a deep red color (other red dyes may be used, but this one is especially good). If the study is made during the summer, the "touch-me-not" (impatiens) will be found a very useful plant, or the garden-balsam, which may also be had in the winter from conservatories. Almost any plant will do, however, but we should also select one like the corn plant (zea mays) if in the summer, or the petioles of a plant like caladium, which can be obtained from the conservatory. If seedlings of the castor-oil bean are at hand we may cut off some shoots which are 8–10 inches high, and place them in the solution also.

95. These solutions color the tracts in the stem and leaves through which they flow.—After a few hours in the case of the impatiens, or the more tender plants, we can see through the stem that certain tracts are colored red by the solution, and after 12 to 24 hours there may be seen a red coloration of the

leaves of some of the plants used. After the shoots have been standing in the solution for a few hours, if we cut them at various places we will note that there are several points in the section where the tissues are colored red. In the impatiens perhaps from four to five, in the sunflower a larger number. In these plants the colored areas on a cross section of the stem are situated in a concentric ring which separates more or less completely an outer ring of the stem from the central portion. If we now split portions of the stem lengthwise we see that these colored areas continue throughout the length of the stem, in some cases even up to the leaves and into them.

96. If we cut across the stem of a corn plant which has been in the solution, we see that instead of the colored areas being in a concentric ring they are irregularly scattered, and on splitting

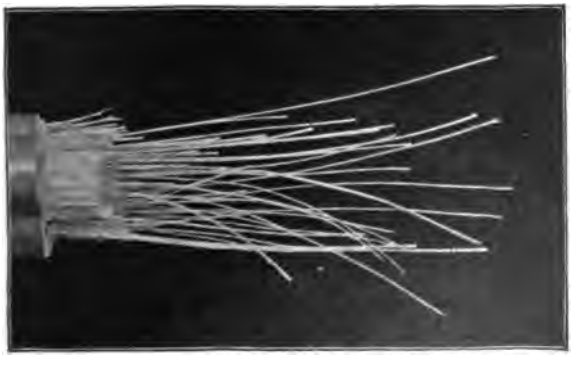

Fig. 57.
Broken corn stalk, showing fibro-vascular bundles.

the stem we see here also that these colored areas extend for long distances through the stem. If we take a corn stem which is mature, or an old and dead one, cut around through the outer hard tissues, and then break the stem at this point, from the softer tissue long strings of tissue will pull out as shown in fig. 57. These strings of denser tissue correspond to the areas which are colored by the dye. They are in the form of minute bundles, and are called *vascular bundles*.

97. We thus see that instead of the liquids passing through the entire stem they are confined to definite courses. Now that we have discovered the path of the upward movement of water in the stem, we are curious to see what the structure of these definite portions of the stem is.

98. Structure of the fibro-vascular bundles.—We should now make quite thin cross sections, either free hand and mount in water for microscopic examination, or they may be made with a microtome and mounted in Canada balsam, and in this condition will answer for future study. To illustrate the structure of the bundle in one type we may take the stem of the castor-oil bean. On examining these cross sections we see that there are groups of cells which are denser than the ground tissue. These groups correspond to the colored areas in the former experiments, and are the vascular bundles

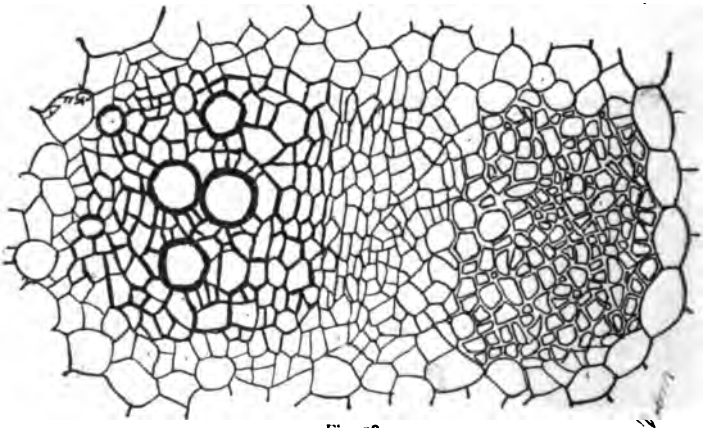

Fig. 58.

Xylem portion of bundle. Cambium portion of bundle. Bast portion of bundle.

Section of vascular bundle of sunflower stem.

cut across. These groups are somewhat oval in outline, with the pointed end directed toward the center of the stem. If we look at the section as a whole we see that there is a narrow continuous ring* of small cells

* This ring and the bundles separate the stem into two regions, an outer one composed of large cells with thin walls, known as the cortical cells, or collectively the *cortex*. The inner portion, corresponding to what is called the pith, is made up of the same kind of cells and is called the *medulla*, or *pith*. When the cells of the cortex, as well as of the pith, remain thin walled the tissue is called parenchyma. Parenchyma belongs to the group of tissues called fundamental.

situated at the same distance from the center of the stem as the middle part of the bundles, and that it divides the bundles into two groups of cells.

99. Woody portion of the bundle.—In that portion of the bundle on the inside of the ring, i.e., toward the "pith," we note large, circular, or angular cavities. The walls of these cells are quite thick and woody. They are therefore called wood cells, and because they are continuous with cells above and below them in the stem in such a way that long tubes are formed, they are called woody vessels. Mixed in with these are smaller cells, some of which also have thick walls and are wood cells. Some of these cells may have thin walls. This is the case with all when they are young, and they are then classed with the fundamental tissue or soft tissue (parenchyma). This part of the bundle, since it contains woody vessels and fibres, is the *wood portion* of the bundle, or technically the *xylem*.

100. Bast portion of the bundle.—If our section is through a part of the stem which is not too young, the tissues of the outer part of the bundle will show either one or several groups of cells which have white and shiny walls, that are thickened as much or more than those of the wood vessels. These cells are *bast* cells, and for this reason this part of the bundle is the *bast* portion, or the *phloem*. Intermingled with these, cells may often be found which have thin walls, unless the bundle is very old. Nearer the center of the bundle and still within the bast portion are cells with thin walls, angular and irregularly arranged. This is the softer portion of the bast, and some of these cells are what are called *sieve* tubes, which can be better seen and studied in a longitudinal section of the stem.

101. Cambium region of the bundle.—Extending across the center of the bundle are several rows of small cells, the smallest of the bundle, and we can see that they are more regularly arranged, usually in quite regular rows, like bricks piled upon one another. These cells have thinner walls than any others of the bundle, and they usually take a deeper stain when treated with a solution of some of the dyes. This is because they are younger, and are therefore richer in protoplasmic contents. This zone of young cells across the bundle is the *cambium*. Its cells grow and divide, and thus increase the size of the bundle. By this increase in the number of the cells of the cambium layer, the outermost cells on either side are continually passing over into the phloem, on the one hand, and into the wood portion of the bundle, on the other hand.

102. Longitudinal section of the bundle.—If we make thin longisections of the vascular bundle of the castor-oil seedling (or other dicotyledon) so that we have thin ones running through a bundle radially, as shown in fig. 59, we can see the structure of these parts of the bundle in side view. We see here that the form of the cells is very different from what is presented in a cross section of the same. The walls of the various ducts have peculiar markings on them. These markings are caused by the walls being thicker in some

places than in others, and this thickening takes place so regularly in some instances as to form regular spiral thickenings. Others have the thickenings

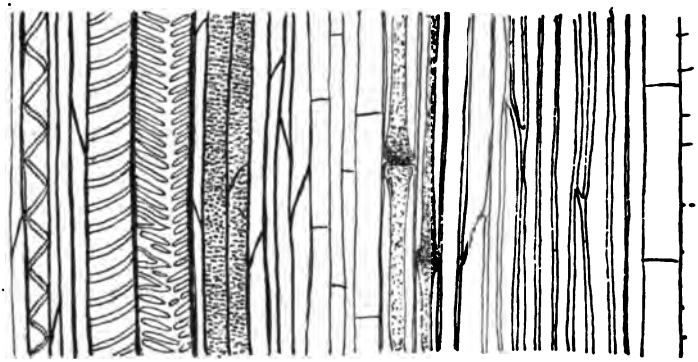

Fig. 59.

Longitudinal section of vascular bundle of sunflower stem; spiral, scalariform and pitted vessels at left; next are wood fibers with oblique cross walls; in middle are cambium cells with straight cross walls, next two sieve tubes, then phloem or bast cells.

in the form of the rounds of a ladder, while still others have pitted walls or the thickenings are in the form of rings.

103. Vessels or ducts.—One way in which the cells in side view differ greatly from an end view, in a cross section in the bundle, is that they are much longer in the direction of the axis of the stem. The cells have become elongated greatly. If we search for the place where two of these large cells with spiral, or ladder-like, markings meet end to end, we see that the wall which formerly separated the cells has nearly or quite disappeared. In other words the two cells have now an open communication at the ends. This is so for long distances in the stem, so that long columns of these large cells form tubes or vessels through which the water rises in the stems of plants.

104. In the bast portion of the bundle we detect the cells of the bast fibers by their thick walls. They are very much elongated and the ends taper out to thin points so that they overlap. In this way they serve to strengthen the stem.

105. Sieve tubes.—Lying near the bast cells, usually toward the cambium, are elongated cells standing end to end, with delicate markings on their cross walls which appear like finely punctured plates or sieves. The protoplasm in such cells is usually quite distinct, and sometimes contracted away from the side walls, but attached to the cross walls, and this aids in the detection of the sieve tubes (fig. 59.) The granular appearance which these plates present is caused by minute perforations through the wall so that there is a communication between the cells. The tubes thus formed are therefore called sieve tubes and they extend for long distances through the tube so that there

is communication throughout the entire length of the stem. (The function of the sieve tubes is supposed to be that for the downward transportation of substances elaborated in the leaves.)

106. If we section in like manner the stem of the sunflower we shall see similar bundles, but the number is greater than eight. In the garden balsam the number is from four to six in an ordinary stem 3–4*mm* diameter. Here we can see quite well the origin of the vascular bundle. Between the larger bundles we can see especially in free-hand sections of stems through which a colored solution has been lifted by transpiration, as in our former experiments, small groups of the minute cells in the cambial ring which are colored. These groups of cells which form strands running through the stem are *procambium strands*. The cells divide and increase just like the cambium cells, and the older ones thrown off on either side change, those toward the center of the stem to wood vessels and fibers, and those on the outer side to bast cells and sieve tubes.

107. Fibrovascular bundles in the Indian corn.—We should now make a thin transection of a portion of the center of the stem of Indian corn, in order to compare the structure of the bundle with that of the plants which we have just examined. In fig. 60 is represented a fibrovascular bundle of the stem of the Indian corn. The large cells are those of the spiral and reticulated and annular vessels. This is the woody portion of the bundle or xylem. Opposite this is the bast portion or phloem, marked by the lighter colored tissue at *i*. The larger of these cells are the sieve tubes, and intermingled with them are smaller cells with thin walls. Surrounding the entire bundle are small cells with thick walls. These are elongated and the tapering ends overlap. They are thus slender and long and form fibers. In such a bundle all of the cambium has passed over into permanent tissue and is said to be closed.

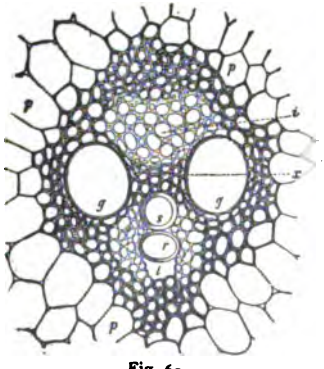

Fig. 60.

Transection of fibrovascular bundle of Indian corn. *a*, toward periphery of stem; *g*, large pitted vessels; *s*, spiral vessel; *r*, annular vessel; *l*, air cavity formed by breaking apart of the cells; *i*, soft bast, a form of sieve tissue; *p*, thin-walled parenchyma. (Sachs.)

108. Rise of water in the vessels.—During the movement of the water or nutrient solutions upward in the stem the vessels of the wood portion of the bundle in certain plants are nearly or quite filled, if root pressure is active and transpiration is not very rapid. If, however, on dry days transpiration is in excess of root pressure, as often happens, the vessels are not filled with the water, but are partly filled with certain gases because the air or other

gases in the plant become rarefied as a result of the excessive loss of water. There are then successive rows of air or gas bubbles in the vessels separated by films of water which also line the walls of the vessels. The condition of the vessel is much like that of a glass tube through which one might pass the "froth" which is formed on the surface of soapy water. This forms a chain of bubbles in the vessels. This chain has been called Jamin's chain because of the discoverer.

109 Why water or food solutions can be raised by the plant to the height attained by some trees has never been satisfactorily explained. There are several theories propounded which cannot be discussed here. It is probably a very complex process. Root pressure and transpiration both play a part, or at least can be shown, as we have seen, to be capable of lifting water to a considerable height. In addition to this, the walls of the vessels absorb water by diffusion, and in the other elements of the bundle capillarity comes also into play, as well as osmosis.

See Organization of Tissues, Chapter 38.

110. Flow of sap in the spring.—The cause of the bleeding of trees and the flow of sap in the spring is little understood. One of the remarkable cases is the flow of sap in maple trees. It begins in early spring and ceases as the buds are opening, and seems to be initiated by alternation of high and low temperatures of day and night. It has been found that the pressures inside of the tree at this time are enormously increased during the day, when the temperature rises after a cold night. This has led to the belief that the pressure is caused by the expansion of the gases in the vascular ducts. The warming up of the twigs and branches of the tree would take place rapidly during the day, while the interior of the trunk would be only slightly affected. The pressures then would cause the sap to flow downward during the day, and at night the branches becoming cool, sap would flow back again from the roots and trunk

Recent experiments by Jones *et al.* show that while some of the pressure is due to the expansion of gas in the tree by the rise of temperature, this cannot account for the enormous pressures which are often present, for example, when after a rise in the temperature of 2° C. there was an increase of 20 lbs. pressure.

Then again, after the cessation of the flow in late spring there are often as great differences between night and day temperatures. It therefore seems reasonable to conclude that the expansion of gases by a rise in temperature is not the direct cause.

Activities of the cells.—It has been suggested by some that the rise in temperature exercises an influence on the protoplasts, or living cells, so that they are stimulated to a special activity resulting in an exudation pressure from the individual cells, which is known to take place. With the fall of

temperature at night this activity would cease and there might result a lessened pressure in the cells. Since the specific activities of cells are known to vary in different plants, and in the same plant at different seasons, some support is gained for this theory, though it is generally believed that the activities of the living cells in the stems are not necessary for the upward flow of water. It must be admitted, however, that at present we know very little about this interesting problem.

CHAPTER VI.

MECHANICAL USES OF WATER.

111. Turgidity of plant parts.—As we have seen by the experiments on the leaves, turgescence of the cells is one of the conditions which enables the leaves to stand out from the stem, and the lamina of the leaves to remain in an expanded position, so that they are better exposed to the light, and to the currents of air. Were it not for this turgidity the leaves would hang down close against the stem.

112. Restoration of turgidity in shoots.—If we cut off a living stem of geranium, coleus, tomato, or "balsam," and allow the leaves to partly wilt so that the shoot loses its turgidity, it is possible for this shoot to regain turgidity. The end may be freshly cut again, placed in a vessel of water, covered with a bell jar and kept in a room where the temperature is suitable for the growth of the plant. The shoot will usually become turgid again from the water which is absorbed through the cut end of the stem and is carried into the leaves where the individual cells become turgid, and the leaves are again expanded. Such shoots, and the excised leaves also, may often be made turgid again by simply immersing them in water, as one of the experiments with the salt solution would teach.

Fig. 61.
Restoration of turgidity (Sachs).

113. Turgidity may be restored more certainly and quickly in a partially wilted shoot in another way. The cut end of the shoot may be inserted in a U tube as shown in fig. 61, the end of the tube around the stem of the plant being made air-tight. The arm

of the tube in which the stem is inserted is filled with water and the water is allowed to partly fill the other arm. Into this other arm is then poured mercury. The greater weight of the mercury causes such pressure upon the water that it is pushed into the stem, where it passes up through the vessels in the stems and leaves, and is brought more quickly and surely to the cells which contain the protoplasm and cell-sap, so that turgidity is more quickly and certainly attained.

114. Tissue tensions.—Besides the turgescence of the cells of the leaves and shoots there are certain tissue tensions without which certain tender and succulent shoots, etc., would be limp, and would droop. There are a number of plants usually accessible, some at one season and some at others, which may be used to illustrate tissue tension.

115. Longitudinal tissue tension.—For this in early summer one may use the young and succulent shoots of the elder (sambucus); or the petioles of rhubarb during the summer and early autumn; or the petioles of richardia. Petioles of caladium are excellent for this purpose, and these may be had at almost any season of the year from the greenhouses, and are thus especially advantageous for work during late autumn or winter. The tension is so strong that a portion of such a petiole 10–15*cm* long is ample to demonstrate it. As we grasp the lower end of the petiole of a caladium, or rhubarb leaf, we observe how rigid it is, and how well it supports the heavy expanded lamina of the leaf.

116. The ends of a portion of such a petiole or other object which may be used are cut off squarely. With a knife a strip from 2–3*mm* in thickness is removed from one side the full length of the object. This strip we now find is shorter than the larger part from which it was removed. The outer tissue then exerts a tension upon the petiole which tends to shorten it. Let us remove another strip lying next this one, and another, and so on until the outer tissues remain only upon one side. The object will now bend toward that side. Now remove this strip and compare the length of the strips removed with the central portion. We find that they are much

shorter now. In other words there is also a tension in the tissue of the central portion of the petiole, the direction of which is opposite to that of the superficial tissue. The parts of the petiole now are not rigid, and they easily bend. These two longitudinal tissue tensions acting in opposition to each other therefore give rigidity to the succulent shoot. It is only when the individual cells of such shoots or petioles are turgid that these tissue tensions in succulent shoots manifest themselves or are prominent.

117. To demonstrate the efficiency of this tension in giving support, let us take a long petiole of caladium or of rhubarb. Hold it by one end in a horizontal position. It is firm and rigid, and does not droop, or but little. Remove all of the outer portion of the tissues, as described above, leaving only the central portion. Now attempt to hold it in a horizontal position by one end. It is flabby and droops downward because the longitudinal tension is removed.

118. Longitudinal tension in dandelion stems.—Take long and fresh dandelion stems. Split them. Note that they coil. The longitudinal tension is very great. Place some of these strips in fresh water. They coil up into close curls because by the absorption of water by the cells the turgescence of the individual cells is increased, and this increases the tension in the stem. Now place them in salt water (a 5 per cent solution). Why do they uncoil?

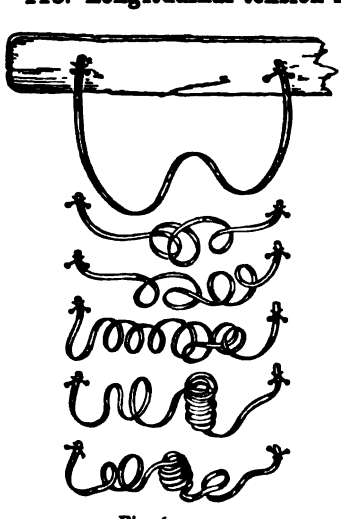

Fig. 62.
Strip from dandelion stem made to imitate a plant tendril.

119. To imitate the coiling of a tendril.—Cut out a narrow strip from a long dandelion stem. Fasten to a piece of soft wood, with the ends close together, as shown in fig. 62. Now place it in fresh water and watch it coil. Part of it coils one way and part another way, just as a ten-

dril does after the free end has caught hold of some place for support.

120. Transverse tissue tension.—To illustrate this one may take a willow shoot 3–5*cm* in diameter and saw off sections about 2*cm* long. Cut through the bark on one side and peel it off in a single strip. Now attempt to replace it. The bark will not quite cover the wood again, since the ends will not meet. It must then have been held in transverse tension by the woody part of the shoot.

CHAPTER VII.

STARCH AND SUGAR FORMATION

1. The Gases Concerned.

121. Gas given off by green plants in the sunlight.—Let us take some green alga, like spirogyra, which is in a fresh condition, and place one lot in a beaker or tall glass vessel of water and set this in the direct sunlight or in a well lighted place. At the same time cover a similar vessel of spirogyra with black cloth so that it will be in the dark, or at least in very weak light.

122. In a short time we note that in the first vessel small bubbles of gas are accumulating on the surface of the threads of the spirogyra, and now and then some free themselves and rise to the surface of the water. Where there is quite a tangle of the threads the gas is apt to become caught and held back in larger bubbles, which on agitation of the vessel are freed.

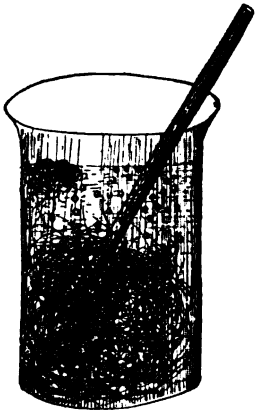

Fig. 63.
Oxygen gas given off by spirogyra

If we now examine the second vessel we see that there are no bubbles, or only a very few of them. We are led to believe then that sunlight has had something to do with the setting free of this gas from the plant.

123. We may now take another alga like vaucheria and perform the experiment in the same way, or to save time the two may be set up at once. In fact if we take any of the green

algæ and treat them as described above gas will be given off in a similar manner.

124. We may now take one of the higher green plants, an aquatic plant like elodea, callitriche, etc. Place the plant in the water with the cut end of the stem uppermost, but still immersed, the plant being weighted down by a glass rod or other suitable object. If we place the vessel of water containing these leafy stems in the bright sunlight, in a short time bubbles of gas will pass off quite rapidly from the cut end of the stem. If in the same vessel we place another stem, from which the leaves have been cut, the number of bubbles of gas given off will be very few. This indicates that a large part of the gas is furnished by the leaves.

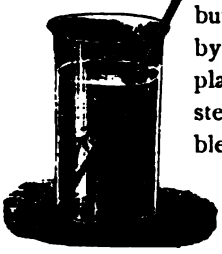

Fig. 64.
Bubbles of oxygen gas given off from elodea in presence of sunlight. (Oels.)

125. Another vessel fitted up in the same way should be placed in the dark or shaded by covering with a box or black cloth. It will be seen here, as in the case of spirogyra, that very few or no bubbles of gas will be set free. Sunlight here also is necessary for the rapid escape of the gas.

126. We may easily compare the rapidity with which light of varying intensity effects the setting free of this gas. After cutting the end of the stem let us plunge the cut surface several times in melted paraffine, or spread over the cut surface a coat of varnish. Then prick with a needle a small hole through the paraffine or varnish. Immerse the plant in water and place in sunlight as before. The gas now comes from the puncture through the coating of the cut end, and the number of bubbles given off during a given period can be ascertained by counting. If we duplicate this experiment by placing one plant in weak light or diffused sunlight, and another in the shade, we can easily compare the rapidity of the escape of the gas under the different conditions, which represent varying intensities of light. We see then that not only is sunlight necessary for the setting free of this gas, but that in diffused light or in the shade the activity of the plant in this respect is less than in direct sunlight.

127. What this gas is.—If we take quite a quantity of the plants of elodea and place them under an inverted funnel which is immersed in water, the gas will be given off in quite large quantities and will rise into the narrow exit of the funnel.

The funnel should be one with a short tube, or the vessel one which is quite deep so that a small test tube which is filled with water may in this condition be inverted over the opening of the funnel tube. With this arrangement of the experiment the gas will rise in the inverted test tube, slowly displace a portion of the water, and become collected in a sufficient quantity to afford us a test. When a considerable quantity has accumulated in the test tube, we may close the end of the tube in the water with the thumb, lift it from the water and invert. The gas will rise against the thumb. A dry soft pine splinter should be then lighted, and after it has burned a short time, extinguish the flame by blowing upon it, when the still burning end of the splinter should be brought to the mouth of the tube as the thumb is quickly moved to one side. The glowing of the splinter shows that the gas is *oxygen*.

Fig. 65.
Apparatus for collecting quantity of oxygen from elodea. (Detmer.)

128. It is better to allow the apparatus to stand several days in the sunlight in order to catch a full tube of the gas. Or on a sunny day carbon dioxide gas can be led into the water in the jar from a generator, such an one as is used for the evolution of CO_2. The CO_2 can be produced by the action of hydrochloric acid on bits of marble. The CO_2 should not be run below the funnel. The test-tube should be fastened so that the light oxygen gas will not raise it off the funnel. With the tube full of gas the test for oxygen can be made by lifting the tube with one hand and

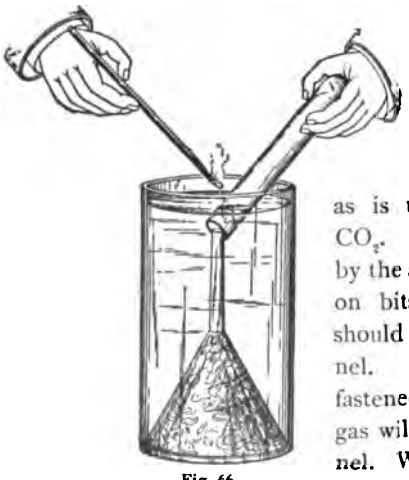

Fig. 66.
Ready to see what the gas is.

quickly thrusting the glowing end of the splinter in with the other hand. If properly handled, the splinter will flame again. If it is necessary to keep the apparatus standing for more than one day it is well to add fresh water in the place of most of the water in the jar. Do not use leaves of land plants in this experiment, since the bubbles which rise when these leaves are placed in water are not evidence that this process is taking place.

Fig. 67.
The splinter lights again in the presence of oxygen gas.

129. Oxygen given off by green land plants also.—If we should extend our experiments to land plants we should find that oxygen is given off by them under these conditions of light. Land plants, however, will not do this when they are immersed in water, but it is necessary to set up rather complicated apparatus and to make analyses of the gases at the beginning and at the close of the experiments. This has been done, however, in a sufficiently large number of cases so that we know that all green plants in the sunlight, if temperature and other conditions are favorable, give off oxygen.

130. Absorption of carbon dioxide.—We have next to inquire where the oxygen comes from which is given off by green plants when exposed to the sunlight, and also to learn something more of the conditions necessary for the process. We know that water which has been for some time exposed to the air and soil, and has been agitated, like running water of streams, or the water of springs, has mixed with it a considerable quantity of oxygen and carbon dioxide.

If we boil spring water or hydrant water which comes from a stream containing oxygen and carbon dioxide, for about 20 minutes, these gases are driven off. We should set this aside where it will not be agitated, until it has cooled sufficiently to receive plants without injury. Let us now place some spirogyra or vaucheria, and elodea, or other green water plant, in this boiled water and set the vessel in the bright sunlight under the same conditions which were employed in the experiments for the evolution of oxygen. No oxygen is given off.

Can it be that this is because the oxygen was driven from the water in boiling? We shall see. Let us take the vessel containing the water, or some other boiled water, and agitate it so that the air will be thoroughly mixed with it. In this way oxygen is again mixed with the water. Now place the plant again in the water, set in the sunlight, and in several minutes observe the result. No oxygen or but little is given off. There must be then some other requisite for the evolution of the oxygen

132. The gases are interchanged in the plants.—We will now introduce carbon dioxide again in the water. This can be done by leading CO_2 from a gas generator into the water. Broken bits of marble are placed in the generator, acted upon by hydrochloric acid, and the gas is led over by glass tubing. Now if we place the plant in the water and set the vessel in the sunlight, in a few minutes the oxygen is given off rapidly.

133. A chemical change of the gas takes place within the plant cell.—This leads us to believe then that CO_2 is in some way necessary for the plant in this process. Since oxygen is given off while carbon dioxide, a different gas, is necessary, it would seem that a chemical change takes place in the gases within the plant. Since the process takes place in such simple plants as spirogyra as well as in the more bulky and higher plants, it appears that the changes go on within the cell, in fact within the protoplasm.

134. Gases as well as water can diffuse through the protoplasmic membrane.—Carbon dioxide then is absorbed by the plant while oxygen is given off. We see therefore that gases as well as water can diffuse through the protoplasmic membrane of plants under certain conditions.

2. Where Starch is Formed.

We have found by these simple experiments that some chemical change takes place within the protoplasm of the green cells of plants during the absorption of carbon dioxide and the giving off of oxygen. We should examine some of the green parts of those plants used in the experiments, or if they are not

at hand we should set up others in order to make this examination.

135. Starch formed as a result of this process.—We may take spirogyra which has been standing in water in the bright sunlight for several hours. A few of the threads should be placed in alcohol for a short time to kill the protoplasm. From the alcohol we transfer the threads to a solution of iodine in potassium iodide. We find that at certain points in the chlorophyll band a bluish tinge, or color, is imparted to the ring or sphere which surrounds the pyrenoid. In our first study of the spirogyra cell we noted this sphere as being composed of numerous small grains of starch which surround the pyrenoid.

136. Iodine used as a test for starch.—This color reaction which we have obtained in treating the threads with iodine is the well-known reaction, or test, for starch. We have demonstrated then that starch is present in spirogyra threads which have stood in the sunlight with free access to carbon dioxide.

If we examine in the same way some threads which have stood in the dark for a few days we obtain no reaction for starch, or at best only a slight reaction. This gives us some evidence that a chemical change does take place during this process (absorption of CO_2 and giving off of oxygen), and that starch is a product of that chemical change.

137. Schimper's method of testing for the presence of starch.—Another convenient and quick method of testing for the presence of starch is what is known as Schimper's method. A strong solution of chloral hydrate is made by taking 8 grams of chloral hydrate for every 5*cc* of water. To this solution is added a little of an alcoholic tincture of iodine. The threads of spirogyra may be placed directly in this solution, and in a few moments mounted in water on the glass slip and examined with the microscope. The reaction is strong and easily seen.

We should also examine the leaves of elodea, or one of the higher green plants which has been for some time in the sunlight. We may use here Schimper's method by placing the leaves directly in the solution of chloral hydrate and iodine.

The leaves are made transparent by the chloral hydrate so that the starch reaction from the iodine is easily detected.

The following is a convenient and safe method of extracting chlorophyll from leaves. Fill a large pan, preferably a dishpan, half full of hot water. This may be kept hot by a small flame. On the water float an evaporating dish partly filled with alcohol. The leaves should be first immersed in the hot water for several minutes, then placed in the alcohol, which will quickly remove the chlorophyll. Now immerse the leaves in the iodine solution.

138. Green parts of plants form starch when exposed to light.—Thus we find that in the case of all the green plants we have examined, starch is present in the green cells of those which

Fig. 68.
Leaf of coleus showing green and white **areas**, before treatment with iodine.

Fig. 69.
Similar leaf treated with iodine, the starch reaction only showing where the leaf was green.

have been standing for some time in the sunlight where the process of the absorption of CO_2 and the giving off of oxygen can go on, and that in the case of plants grown in the dark, or in

leaves of plants which have stood for some time in the dark, starch is absent. We reason from this that starch is the product of the chemical change which takes place in the green cells under these conditions. The CO_2 which is absorbed by the plant mixes with the water (H_2O) in the cell and immediately forms carbonic acid. The chlorophyll in the leaf absorbs radiant energy from the sun which splits up the carbonic acid, and its elements then are put together into a more complex compound, starch. This process of putting together the elements of an organic compound is a *synthesis*, or a *synthetic assimilation*, since it is done by the living plant. It is therefore a synthetic assimilation of carbon dioxide. Since the sunlight supplies the energy it is also called *photosynthesis*, or *photosynthetic assimilation*. We can also say carbon dioxide assimilation, or CO_2 assimilation (see paragraph on assimilation at close of Chapter 10).

139. Starch is formed only in the green parts of variegated leaves.—If we test for starch in variegated leaves like the leaf of a coleus plant, we shall have an interesting demonstration of the fact that the green parts of plants only form starch. We may take a leaf which is partly green and partly white, from a plant which has been standing for some time in bright light. Fig. 68 is from a photograph of such a leaf. We should first boil it in alcohol to remove the green color. Now immerse it in the potassium iodide of iodine solution for a short time The parts which were formerly green are now dark blue or nearly black, showing the presence of starch in those portions of the leaf, while the white part of the leaf is still uncolored. This is well shown in fig. 69, which is from a photograph of another coleus leaf treated with the iodine solution.

3. Chlorophyll and the Formation of Starch.

140. In our experiments thus far in treating of the absorption of carbon dioxide and the evolution of oxygen, with the accompanying formation of starch, we have used green plants.

141. Fungi cannot form starch.—If we should extend our experiments to the fungi, which lack the green color so characteristic of the majority of plants, we should find that photosynthesis does not take place even though the plants are exposed to direct sunlight. These plants cannot then form starch, but obtain carbohydrates for food from other sources.

142. Photosynthesis cannot take place in etiolated plants.—Moreover photosynthesis is usually confined to the green plants, and if by any means one of the ordinary green plants loses its green color this process cannot take place in that plant, even when brought into the sunlight, until the green color has appeared under the influence of light.

This may be very easily demonstrated by growing seedlings of the bean, squash, corn, pea, etc. (pine seedlings are green even when grown in the dark), in a dark room, or in a dark receiver of some kind which will shut out the rays of light. The room or receiver must be quite dark. As the seedlings are "coming up," and as long as they remain in the dark chamber, they will present some other color than green; usually they are somewhat yellowed. Such plants are said to be *etiolated*. If they are brought into the sunlight now for a few hours and then tested for the presence of starch the result will be negative. But if the plant is left in the light, in a few days the leaves begin to take on a green color, and then we find that carbon dioxide assimilation begins.

143. Chlorophyll and chloroplasts.—The green substance in plants is then one of the important factors in this complicated process of forming starch. This green substance is *chlorophyll*, and it usually occurs in definite bodies, the chlorophyll bodies, or *chloroplasts*.

The material for new growth of plants grown in the dark is derived from the seed. Plants grown in the dark consist largely of water and protoplasm, the walls being very thin.

144. Form of the chlorophyll bodies.—Chlorophyll bodies vary in form in some different plants, especially in some of the

lower plants. This we have already seen in the case of spirogyra, where the chlorophyll body is in the form of a very irregular band, which courses around the inner side of the cell wall in a spiral manner. In zygnema, which is related to spirogyra, the chlorophyll bodies are star-shaped. In the desmids the form varies greatly. In œdogonium, another of the thread-like algæ, illustrated in fig. 144, the chlorophyll bodies

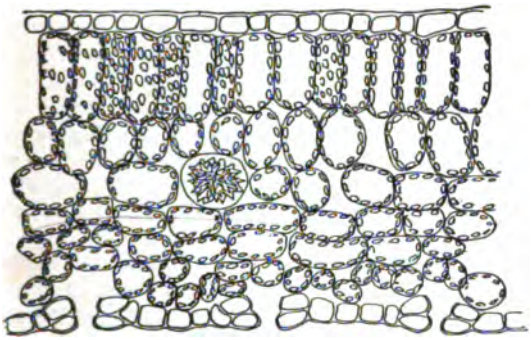

Fig. 69*a*.

Section of ivy leaf, palisade cells above, loose parenchyma, with large intercellular spaces in center. Epidermal cells on either edge, with no chlorophyll bodies.

are more or less flattened oval disks. In vaucheria, too, a branched thread-like alga shown in fig. 138, the chlorophyll bodies are oval in outline. These two plants, œdogonium and vaucheria, should be examined here if possible, in order to become familiar with their form, since they will be studied later under morphology (see chapters on œdogonium and vaucheria, for the occurrence and form of these plants). The form of the chlorophyll body found in œdogonium and vaucheria is that which is common to many of the green algæ, and also occurs in the mosses, liverworts, ferns, and the higher plants. It is a more or less rounded, oval, flattened body.

145. Chlorophyll is a pigment which resides in the chloroplast.—That the chlorophyll is a coloring substance which resides in the chloroplastid, and does not form the body itself, can be demonstrated by dissolving out the chlorophyll when the framework of the chloroplastid is apparent. The green parts of plants which have been placed for some time in alcohol lose

their green color. The alcohol at the same time becomes tinged with green. In sectioning such plant tissue we find that the chlorophyll bodies, or chloroplastids as they are more properly called, are still intact, though the green color is absent. From this we know that chlorophyll is a substance distinct from that of the chloroplastid.

146. Chlorophyll absorbs energy from sunlight for photosynthesis. —It has been found by analysis with the spectroscope that chlorophyll absorbs certain of the rays of the sunlight. The energy which is thus obtained from the sun, called *kinetic* energy, acts on the molecules of CH_2O_2, separating them into molecules of C, H, and O. (When the CO_2 from the air enters the plant cell it immediately unites with some of the water, forming carbonic acid = CH_2O_2.) After a series of complicated chemical changes starch is formed by the union of carbon, oxygen, and hydrogen. In this process of the reduction of the CH_2O_2 and the formation of starch there is a surplus of oxygen, which accounts for the giving off of oxygen during the process.

147. Rays of light concerned in photosynthesis. — If a solution of chlorophyll be made, and light be passed through it, and this light be examined with the spectroscope, there appear what are called absorption bands. These are dark bands which lie across certain portions of the spectrum. These bands lie in the red, orange, yellow, green, blue, and violet, but the bands are stronger in the red, which shows that chlorophyll absorbs more of the red rays of light than of the other rays. These are the rays of low refrangibility. The kinetic energy derived by the absorption of these rays of light is transformed into potential energy. That is, the molecule of CH_2O_2 is broken up, and then by a different combination of certain elements starch is formed.*

148. Starch grains formed in the chloroplasts.—During photosynthesis the starch formed is deposited generally in small grains within the green chloroplast in the leaf. We can see this easily by examining the leaves of some moss like funaria which has been in the light, or in the chloroplasts of the prothallia of ferns, etc. Starch grains may also be formed in the chloroplasts from starch which was formed in some other part of the plant, but

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* In the formation of starch during photosynthesis the separated molecules from the carbon dioxide and water unite in such a way that carbon, hydrogen, and oxygen are united into a molecule of starch. This result is usually represented by the following equation: $CO_2 + H_2O = CH_2O + O_2$. Then by polymerization $6(CH_2O) = C_6H_{12}O_6$ = grape sugar. Then $C_6H_{12}O_6 - H_2O = C_6H_{10}O_5$ = starch. It is believed, however, that the process is much more complicated than this, that several different compounds are formed before starch finally appears, and that the formula for starch is much higher numerically than is represented by $C_6H_{10}O_5$.

which has passed in solution. Thus the functions of the chloroplast are twofold, that of photosynthesis and the formation of starch grains.

149. In the translocation of starch when it becomes stored up in various parts of the plant, it passes from the state of solution into starch grains in connection with plastids similar to the chloroplasts, but which are not green. The green ones are sometimes called *chloroplasts*, while the colorless ones are termed *leucoplasts*, and those possessing other colors, as red and yellow, in floral leaves, the root of the carrot, etc., are called *chromoplasts*.

150. Photosynthesis in other than green plants.—While carbohydrates are usually only formed by green plants, there are some exceptions. Apparent exceptions are found in the blue-green algæ, like oscillatoria, nostoc, or in the brown and red sea weeds like fucus, rhabdonia, etc. These plants, however, possess chlorophyll, but it is disguised by another pigment or color. There are plants, however, which do not have chlorophyll and yet form carbohydrates with evolution of oxygen in the presence of light, as for example a purple bacterium, in which the purple coloring substance absorbs light, though the rays absorbed most energetically are not the red.

151. Influence of light on the movement of chlorophyll bodies.—*In fern prothallia.*—If we place fern prothallia in weak light for a few hours, and then examine them under the microscope, we find that the most of the chlorophyll bodies in the cells are arranged along the inner surface of the horizontal wall. If now the same prothallia are placed in a brightly lighted place for a short time most of the chlorophyll bodies move so that they are

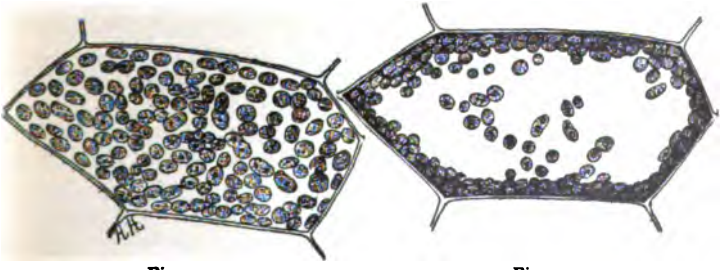

Fig. 70.
Cell exposed to weak diffused light showing chlorophyll bodies along the horizontal walls.

Fig. 71.
Same cell exposed to strong light, showing chlorophyll bodies have moved to perpendicular walls.

Figs. 70, 71.—Cell of prothallium of fern.

arranged along the surfaces of the perpendicular walls, and instead of having the flattened surfaces exposed to the light as in the former case, the edges of the chlorophyll bodies are now turned toward the light. (See figs.

70, 71.) The same phenomenon has been observed in many plants. Light then has an influence on chlorophyll bodies, to some extent determining their position. In weak light they are arranged so that the flattened surfaces are exposed to the incidence of the rays of light, so that the chlorophyll will absorb as great an amount as possible of kinetic energy; but intense light is stronger than necessary, and the chlorophyll bodies move so that their edges are exposed to the incidence of the rays. This movement of the chlorophyll bodies is different from that which takes place in some water plants like elodea The chlorophyll bodies in elodea are free in the protoplasm. The protoplasm in the cells of elodea streams around the inside of the cell wall much as it does in nitella and the chlorophyll bodies are carried along in the currents, while in nitella they are stationary.

CHAPTER VIII.

STARCH AND SUGAR CONCLUDED. ANALYSIS OF PLANT SUBSTANCE.

1. Translocation of Starch.

152. Translocation of starch.—It has been found that leaves of many plants grown in the sunlight contain starch when examined after being in the sunlight for several hours. But when the plants are left in the dark for a day or two the leaves contain no starch, or a much smaller amount. This suggests that starch after it has been formed may be transferred from the leaves, or from those areas of the leaves where it has been formed.

To test this let us perform an experiment which is often made. We may take a plant such as a garden tropæolum or a clover plant, or other land plant in which it is easy to test for the presence of starch. Pin a piece of circular cork, which is smaller than the area of the leaf, on either side of the leaf, as in fig. 72, but allow free circulation of air between the cork and the under side of the leaf. Place the plant where it will be in the sunlight. On the afternoon of the following day, if the sun has been shining, test the entire leaf for starch. The part covered by the cork will not give the reaction for starch, as shown by the absence of the bluish color, while the other parts of the leaf will show it. The starch which was in that part of the leaf the day before was dissolved and removed during the night, and then during the following day, the parts being covered from the light, no starch was formed in them.

Fig. 72.
Leaf of tropæolum with portion covered with corks to prevent the formation of starch. (After Detmer.)

Fig. 73.
Leaf of tropæolum treated with iodine after removal of cork, to show that starch is removed from the leaf during the night.

153. Starch in other parts of plants than the leaves.—We may use the iodine test to search for starch in other parts of plants than the leaves. If we cut a potato tuber, scrape some of the cut surface into a pulp, and apply the iodine test, we obtain a beautiful and distinct reaction showing the presence of starch. Now we have learned that starch is only formed in the parts containing chlorophyll. We have also learned that the starch which has been formed in the leaves disappears from the leaf or is transferred from the leaf. We judge therefore that the starch which we have found in the tuber of the potato was formed first in the green leaves of the plant, as a result of photosynthesis. From the leaves it is transferred in solution to the underground stems, and stored in the tubers. The starch is stored here by the plant to provide food for the growth of new plants from the tubers, which are thus much more vigorous than the plants would be if grown from the seed.

154. Form of starch grains.—Where starch is stored as a reserve material it occurs in grains which usually have certain characters peculiar to the species of plant in which they are found. They vary in size in many different plants, and to some extent in form also. If we scrape some of the cut surface of the potato tuber into a pulp and mount a small quantity in water, or make a thin section for microscopic examination, we find large starch grains of a beautiful structure. The grains are oval in form and more or less irregular in outline. But the striking peculiarity is the presence of what seem to be alternating dark and light lines in the starch grain. We note that the lines form irregular rings, which are smaller and smaller until we come to the small central spot termed the "hilum" of the starch grain. It is supposed that these apparent lines in the starch grain are caused by the starch substance being deposited in alternating dense and dilute layers, the dilute layers containing more water than the dense ones; others think that the successive layers from the hilum outward are regularly of diminishing density, and that this gives the appearance of alternating lines. The starch formed by plants is one of the organic substances which are manufactured by plants, and it (or glucose) is the basis for the formation of other organic substances in the plant. Without such organic substances green plants cannot make any appreciable increase of plant substance, though a considerable increase in size of the plant may take place.

NOTE.—The organic compounds resulting from photosynthesis, since they are formed by the union of carbon, hydrogen, and oxygen in such a way that the hydrogen and oxygen are usually present in the same propor-

tion as in water, are called *carbohydrates*. The most common carbohydrates are sugars (cane sugar, $C_{12}H_{22}O_{11}$, for example, in beet roots, sugar cane, sugar maple, etc.), starch, and cellulose.

155. Vaucheria.—The result of carbon dioxide assimilation in the threads of Vaucheria is not clearly understood. Starch is absent or difficult to find in all except a few species, while oil globules are present in most species. These oil globules are spherical, colorless, globose and highly refringent. Often small ones are seen lying against chlorophyll bodies. Oil is a *hydrocarbon* (containing C, H, and O, but the H and O are in different proportions from what they are in H_2O) and until recently it was supposed that this oil in Vaucheria was the direct result of photosynthesis. But the oil does not disappear when the plant is kept for a long time in the dark, which seems to show that it is not the direct product of carbon dioxide assimilation, and indicates that it comes either from a temporary starch body or from glucose. Schimper found glucose in several species of Vaucheria, and Waltz says that some starch is present in Vaucheria sericea, while in V. tuberosa starch is abundant and replaces the oil. To test for oil bodies in Vaucheria treat the threads with weak osmic acid, or allow them to stand for twenty-four hours in Fleming's solution (which contains osmic acid). Mount some threads and examine with microscope. The oil globules are stained black.

2. Sugar, and Digestion of Starch.*

156. The sugar produced as the result of photosynthesis may be stored as sugar or changed to starch. In general sugar is more common in the green parts of monocotyledonous plants, while starch is most frequent in dicotyledons. Plant sugars are of three general kinds: *cane sugar* or *sucrose*, abundant in the sugar cane, sugar beet, sugar maple, etc.; *glucose* or *fruit sugar*, found in the fruit of a majority of plants, and abundant in some, as in apples, pears, grapes, etc. (in many fruits and other parts of plants both glucose and cane sugar are present); and *maltose*, as in malted barley.

157*a*. Test for sugars.—Make a weak solution of pure commercial grape sugar (glucose) and also one of pure granulated cane sugar. Partly fill two test tubes with Fehling's solution.† To one add some of the grape-sugar solution and to the other add some of the cane-sugar solution. After these tubes have stood in a warm place a few hours, it will be found that a bright orange-brown or cinnabar-colored precipitate of copper and cuprous oxide has formed in the tube containing grape sugar, while the other solution is unchanged. Grape sugar or glucose therefore reduces Fehling's solution, while cane sugar as such has no effect upon it.

157*b*. Test for cane sugar.—Place a small quantity of pure granulated cane sugar in a test tube and add about 15 cc. of distilled water. To

* Paragraphs 156–160 were prepared by Dr. E. J. Durand.

† See page 712 for formula for Fehling's solution.

this add 1 to 2 cc. of cobaltous nitrate solution (5 grams cobalt nitrate in 100 cc. distilled water. Keep in a stoppered bottle), then add a small quantity of a strong sodium hydrate solution (50 grams caustic soda, in sticks, to 100 cc. distilled water. Keep in a bottle). A beautiful violet color appears. Test glucose or grape sugar in the same way and a blue color appears, which gradually changes to green.

157*c*. Cane sugar (sucrose) can be changed to glucose or invert sugar in the following way: To a weak solution of pure granulated cane sugar in a small beaker add a few drops of strong hydrochloric acid, rest on gauze wire, and boil for a minute or two over a flame. This inverts the cane sugar to glucose (equal parts of dextrose and lævulose). To test for the invert sugar the acid must be neutralized. Add sodium carbonate until on adding no effervescence takes place. Now add the Fehling's solution and boil; the red precipitate appears, showing that it reduces Fehling's solution.

158*a*. Tests for sugar in plant tissue.—Scrape out a little of the tissue from the inside of a ripe apple or pear, place it with a little water in a test tube, and add a few drops of Fehling's solution. After standing half an hour the characteristic precipitate of copper and cuprous oxide appears, showing that grape sugar is present in quantity.

Make thin sections of the apple and mount in a drop of Fehling's solution on a slide. After an hour examine with the microscope. The granules of cuprous oxide are present in the cells of the tissue in great abundance.

158*b*. Prepare another tube with some of the pulp in 15 cc. of water; add 2 cc. of cobaltous nitrate solution, and then some of the strong sodium hydrate solution, as in paragraph 157*b*. Cane sugar as well as grape sugar is present in these fruits.

158*c*. Cut up several leaves of a vigorous young Indian corn seedling in a small beaker and add 25 or 30 cc. distilled water. Boil for one or two minutes. Filter. In another small beaker boil Fehling's solution, and if it is free from sediment (if not, filter) add a portion of the filtered corn-leaf solution and boil for two minutes. Hold the beaker toward the light and look on the bottom for the red precipitate. Filter. The red precipitate shows the presence of glucose (or invert sugar). Take the remaining portion of the corn-leaf decoction in a test tube and test for cane sugar by adding cobaltous nitrate and sodium hydrate as in paragraph 157*b*. If the violet color does not appear at once, do not agitate it, but allow it to stand for a while. The violet color appears at the bottom of the tube, showing the presence of cane sugar, while the reaction for glucose may appear in the upper portion of the solution. For comparison take similar corn leaves, remove the chlorophyll with alcohol, and test with iodine. No starch reaction appears. The carbohydrate in corn leaves is therefore sugar and not starch. If now the grain of corn be examined the cells will be found to be full of starch grains, which give the beautiful blue reaction

with iodine. This experiment shows that sugar is formed in the leaves of the Indian corn plant, but is changed to starch when stored in the seed.

158*d*. Take several leaves of bean seedlings; test for glucose and cane sugar as in 158*c*. Both are present. Test a leaf for starch. It is present.

158*e*. Select a branch of sugar maple during autumn, winter, or spring, about 1 cm. in diameter. From a portion scrape off all the bark so as to remove all the color. Cut off some shavings of the white woody portion and boil in a small beaker for one or two minutes. Filter and test for the presence of both glucose and cane sugar as in paragraphs 158*c* and 157*b*. Both are present (at least in several tests made in December, 1906). The bark is to be removed, since the coloring matter in it also reduces Fehling's solution.

158*f*. Scrape some pulp from the inside of a sugar beet. Mix in distilled water in two test tubes. Test one for glucose and the other for cane sugar. Cane sugar is present.

159. How starch is changed to sugar.—We have seen that in many plants the carbohydrate formed as the result of carbon dioxide assimilation is stored as starch. This substance being insoluble in water must be changed to sugar, which is soluble before it can be used as food or transported to other parts of the plant. This is accomplished through the action of certain enzymes, principally diastase. This substance has the power of acting upon starch under proper conditions of temperature and moisture, causing it to take up the elements of water, and so to become sugar.

This process takes place commonly in the leaves where starch is formed, but especially in seeds, tubers (during the sprouting, etc.), and other parts which the plant uses as storehouses for starch food. It is probable that the same conditions of temperature and moisture which favor germination or active growth are also favorable to the production of diastase.

160. Experiments to show the action of diastase.—(*a*) Place a bit of starch half as large as a pea in a test tube, and cover with a weak solution * (about ½ per cent) of commercial taka diastase. After it has stood in a warm place for five or ten minutes test with Fehling's solution. The precipitate of cuprous oxide appears showing that some of the starch has been changed to sugar. By using measured quantities, and by testing with iodine at frequent intervals, it can be determined just how long it takes a given quantity of diastase to change a known quantity of starch. In this connection one should first test a portion of the same starch with Fehling's solution to show that no sugar is present.

(*b*) Repeat the above experiment using a little tissue from a potato, and some from a corn seed.

(*c*) Take 25 germinating barley seeds in which the radicle is just appear-

* This solution of taka diastase should be made up cold. If it is heated to 60° C. or over it is destroyed.

ing. Grind up thoroughly in a mortar with about three parts of water. After this has stood for ten or fifteen minutes, filter. Fill a test tube one-third full of water, add a piece of starch half the size of a pea or less, and boil the mixture to make starch-paste. Add the barley extract. Put in a warm place and test from time to time with iodine. The first samples so treated will be blue, later ones violet, brown, and finally colorless, showing that the starch has all disappeared. This is due to the action of the diastase which was present in the germinating seeds, and which was dissolved out and added to the starch mixture. The office of this diastase is to change the starch in the seeds to sugar. Germinating wheat is sweet, and it is a matter of common observation that bread made from sprouted wheat is sweet.

(*d*) Put a little starch-paste in a test tube and cover it with saliva from the mouth. After ten or fifteen minutes test with Fehling's solution. A strong reaction appears showing how quickly and effectively saliva acts in converting starch to sugar. Successive tests with iodine will show the gradual disappearance of the starch.

161. These experiments have shown us that diastase from three different sources can act upon starch converting it into sugar. The active principle in the saliva is an *animal* diastase (*ptyalin*), which is necessary as one step in the digestion of starch food in animals. The *taka* diastase is derived from a fungus (Eurotium oryzæ) which feeds on the starch in rice grains converting it into sugar which the fungus absorbs for food. The *malt* diastase and *leaf* diastase are formed by the seed plants. That in seeds converts the starch to sugar which is absorbed by the embryo for food. That in the leaf converts the starch into sugar so that it can be transported to other parts of the plant to be used in building new tissue, or to be stored again in the form of starch (example, the potato, in seeds, etc.). The starch is formed in the leaf during the daylight. The light renders the leaf diastase inactive. But at night the leaf diastase becomes active and converts the starch made during the day. Starch is not soluble in water, while the sugar is, and the sugar in solution is thus easily transported throughout the plant. In those green plants which do not form starch in their leaves (sugar beet, corn, and many monocotyledons), grape sugar and fruit sugar are formed in the green parts as the result of photosynthesis. In some, like the corn, the grape sugar formed in the leaves is transported to other parts of the plant, and some of it is stored up in the seed as starch. In others like the sugar beet the glucose and fruit sugar formed in the leaves flow to other parts of the plant, and much of it is stored up as cane sugar in the beet root. The process of photosynthesis probably proceeds in the same way in all cases up to the formation of the grape sugar and fruit sugar in the leaves. In the beet, corn, etc., the process stops here, while in the bean, clover, and most dicotyledons the process is carried one step farther in the leaf and starch is formed.

3. Rough Analysis of Plant Substance.

162. Some simple experiments to indicate the nature of plant substance.—After these building-up processes of the plant, it is instructive to perform some simple experiments which indicate roughly the nature of the plant substance, and serve to show how it can be separated into other substances, some of them being reduced to the form in which they existed when the plant took them as food. For exact experiments and results it would be necessary to make chemical analyses.

163. The water in the plant.—Take fresh leaves or leafy shoots or other fresh plant parts. Weigh. Permit them to remain in a dry room until they are what we call "dry." Now weigh. The plants have lost weight, and from what we have learned in studies of transpiration this loss in weight we know to result from the loss of water from the plant.

164. The dry plant material contains water.—Take air-dry leaves, shavings, or other dry parts of plants. Place them in a test tube. With a holder rest the tube in a nearly horizontal position, with the bottom of the tube in the flame of a Bunsen burner. Very soon, before the plant parts begin to "burn," note that moisture is accumulating on the inner surface of the test tube. This is water driven off which could not escape by drying in air, without the addition of artificial heat, and is called "hygroscopic water."

165. Water formed on burning the dry plant material.—Light a soft-pine or bass-wood splinter. Hold a thistle tube in one hand with the bulb downward and above the flame of the splinter. Carbon will be deposited over the inner surface of the bulb. After a time hold the tube toward the window and look through it above the carbon. Drops of water have accumulated on the inside of the tube. This water is formed by the rearrangement of some of the hydrogen and oxygen, which is set free by the burning of the plant material, where they were combined with carbon, as in the cellulose, and with other elements.

166. Formation of charcoal by burning.—Take dried leaves, and shavings from some soft wood. Place in a porcelain crucible, and cover about 3 cm. deep with dry fine earth. Place the crucible in the flame of a Bunsen burner and let it remain for about fifteen minutes. Remove and empty the contents. If the flame was hot the plant material will be reduced to a good quality of charcoal. The charcoal consists largely of carbon.

167. The ash of the plant.—Place in the porcelain crucible dried leaves and shavings as before. Do not cover with earth. Place the crucible in the flame of the Bunsen burner, and for a moment place on the porcelain cover; then remove the cover, and note the moisture on the under surface from the escaping water. Permit the plant material to burn; it may even flame for a time. In the course of fifteen minutes it is reduced to a whitish

powder, much smaller in bulk than the charcoal in the former experiment. This is the ash of the plant.

168. What has become of the carbon?—In this experiment the air was not excluded from the plant material, so that oxygen combined with carbon as the water was freed, and formed carbon dioxide, passing off into the air in this form. This it will be remembered is the form in which the plant took the carbon-food in through the leaves. Here the carbon dioxide met the water coming from the soil, and the two united to form, ultimately, starch, cellulose, and other compounds of carbon; while with the addition of nitrogen, sulphur, etc., coming also from the soil, still other plant substances were formed.

169. The carbohydrates are classed among the non-nitrogenous substances. Other non-nitrogenous plant substances are the organic acids like oxalic acid ($H_2C_2O_4$), malic acid ($H_2C_4H_4O_5$), etc.; the fats and fixed oils, which occur in the seeds and fruits of many plants. Of the nitrogenous substances the proteids have a very complex chemical formula and contain carbon, hydrogen, oxygen, nitrogen, sulphur, etc. (example, *aleuron*, or proteid grains, found in seeds). The proteids are the source of nitrogenous food for the seedling during germination. Of the amides, *asparagin* ($C_4H_8N_2O_3$) is an example of a nitrogenous substance; and of the alkaloids, nicotin ($C_{10}H_{14}N_2$) from tobacco.

All living plants contain a large per cent of water. According to Vines "ripe seeds dried in the air contain 12 to 15 per cent of water, herbaceous plants 60 to 80 per cent, and many water-plants and fungi as much as 95 per cent of their weight." When heated to 100° C. the water is driven off. The dry matter remaining is made up partly of organic compounds, examples of which are given above, and inorganic compounds. By burning this dry residue the organic substances are mostly changed into volatile products, principally carbonic acid, water, and nitrogen. The inorganic substances as a result of combustion remain as a white or gray powder, the *ash*.

The amount of the ash increases with the age of the plant, though the percentage of ash may vary at different times in the different members of the plant. The following table taken from Vines will give an idea of the amount and composition of the ash in the dry solid of a few plants:

CONTENT OF 1000 PARTS OF DRY SOLID MATTER.

	Ash.	Potash.	Soda.	Lime.	Magnesium.	Ferric Oxide.	Phosphoric Acid.	Sulphuric Acid.	Silica.	Chlorine.
Clover, in blossom	68.3	21.96	1.39	24.06	7.44	0.72	6.74	2.06	1.62	2.66
Wheat, grain.	19.7	6.14	0.44	0.66	2.36	0.26	9.26	0.07	0.42	0.04
Wheat, straw. . . .	53.7	7.33	0.74	3.00	1.33	0.33	2.58	1.32	36.25	0.90
Potato tubers. . . .	37.7	22.76	0.99	0.97	1.77	0.45	6.53	2.45	0.80	1.17
Apples.	14.4	5.14	3.76	0.59	1.26	0.20	1.96	0.88	0.62	.....
Peas (the seed). . .	27.3	11.41	0.26	1.36	2.17	0.16	9.95	0.95	0.24	0.42

CHAPTER IX.

HOW PLANTS OBTAIN THEIR FOOD. I.

1. Sources of Plant Food.

170. The necessary constituents of plant food.—As indicated in Chapter 3, investigation has taught us the principal constituents of plant food. Some suggestion as to the food substances is derived by a chemical analysis of various plants. In Chapter 8 it was noted that there are two principal kinds of compounds in plant substances, the organic compounds and the inorganic compounds or mineral substances. The principal elements in the organic compounds are *hydrogen*, *carbon*, *oxygen* and *nitrogen*. The elements in the inorganic compounds which have been found indispensable to plant growth are *calcium*,* *potassium*, *magnesium*, *phosphorus*, *sulphur* and *iron*. (See paragraphs 54–58, and complete observations on water cultures.) Other elements are found in the ash of plants; and while they are not absolutely necessary for growth, some † of them are beneficial in one way or another.

171. The carbohydrates are derived, as we have learned, from the CO_2 of the air, and water in the plant tissue drawn from the soil; though in the case of aquatic plants entirely submerged, all the constituents are absorbed from the surrounding water.

172. Food substances in the soil.—Land plants derive their mineral food from the soil, the soil received the mineral substances from dissolving and disintegrating rocks. Nitrogenous food is chiefly derived from the same source, but under a variety of conditions which will be discussed in later paragraphs, but the nitrogen comes primarily from the air. Some of the mineral substances, those which are soluble as well as some of the nitrogenous substances, are found in solution in the soil. These are absorbed by the plant, as needed, along with water, through the root hairs.

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* Calcium is not essential for the growth of the fungi.

† For example, silicon is used by some plants in strengthening supporting tissues. Buckwheat thrives better when supplied with a chloride.

173. Absorption of soluble substances.—Since these substances are dissolved in the water of the soil, it is not necessary for us to dwell on the process of absorption. This in general is dwelt upon in Chapter 3. It should be noted, however, that food substances in solution, during absorption, diffuse through the protoplasmic membrane independently of each other and also independently of the rate of movement of the water from the soil into the root hairs and cells of the root.

When the cells have absorbed a certain amount of a given substance, no more is absorbed until the concentration of the cell-sap in that particular substance is reduced. This, however, does not interfere with the absorption of water, or of other substances in solution by the same cells. Plants have therefore a certain selective power in the absorption of food substances.

174. Action of root hairs on insoluble substances. Acidity of root hairs.—If we take a seedling which has been grown in a germinator, or in the folds of cloths or paper, so that the roots are free from the soil, and touch the moist root hairs to blue litmus paper, the paper becomes red in color where the root hairs have come in contact. This is the reaction for the presence of an acid salt, and indicates that the root hairs excrete certain acid substances. This acid property of the root hairs serves a very important function in the preparation of certain of the elements of plant food in the soil. Certain of the chemical compounds of potash, phosphoric acid, etc., become deposited on the soil particles, and are not soluble in water. The acid of the root hairs dissolves some of these compounds where the particles of soil are in close contact with them, and the solutions can then be taken up by the roots. Carbonic acid and other acids are also formed in the soil, and aid in bringing these substances into solution.

175. This corrosive action of the roots can be shown by the well-known experiment of growing a plant on a marble plate which is covered by soil In lieu of the marble plate, the peas may be planted in clam or oyster shells, which are then buried in the soil of the pot, so that the roots of the seedlings will come in contact with the smooth surface of the shell. After a few weeks, if the soil be washed from the marble where the roots have been in close contact, there will be an outline of this part of the root system. Several different acid substances are excreted from the roots of plants which have been found to redden blue litmus paper by contact Experiments by Czapek show, however, that the carbonic acid excreted by the roots has the power of directly bringing about these corrosion phenom-

ena. The acid salts are the substances which are most actively concerned in reddening the blue litmus paper. They do not directly aid in the corrosion phenomena. In the soil, however, where these compounds of potash, phosphoric acid, etc., are which are not soluble in water, the acid salt (primary acid potassium phosphate) which is most actively concerned in reddening the blue litmus paper may act indirectly on these mineral substances, making them available for plant food. This salt soon unites with certain chlorides in the soil, making among other things small quantities of hydrochloric acid.

176. NOTE.—It is a general rule that plants cannot take solid food into their bodies, but obtain all food in either a liquid or gaseous state. The only exception to this is in the case of the plasmodia of certain *Myxomycetes* (Slime Moulds), and also perhaps some of the Flagellates and other very low forms, which engulf solid particles of food. It is uncertain, however, whether these organisms belong to the plant or animal kingdom, and they probably occupy a more or less intermediate position.

177. Action of nitrite and nitrate bacteria.—Many of the higher green plants prefer their nitrogenous food in the form of nitrates. (Example, nitrate of soda, potassium nitrate, saltpetre.) Nitrates are constantly being formed in soil by the action of certain bacteria. The nitrite bacteria (Nitromonas) convert ammonia in the soil to *nitrous acid* (a *nitrite*), while at this point the nitrate bacteria (Nitrobacter) convert the nitrites into nitrates. The fact that this nitrification is going on constantly in soil is of the utmost importance, for while commercial nitrates are often applied to the soil, the nitrates are easily washed from the soil by heavy rains. These nitrite and nitrate bacteria require oxygen for their activity, and they are able to obtain their carbohydrates by decomposing organic matter in the soil, or directly by assimilating the CO_2 in the soil, deriving the energy for the assimilation of the carbon dioxide from the chemical process of nitrification. This kind of carbon dioxide assimilation is called *chemosynthetic* assimilation.

2. Parasites and Saprophytes.

178. Parasites among the fungi.—A parasite is an organism which derives all or a part of its food directly from another living organism (its host) and at the latter's expense. The larger number of plant parasites are found among the fungi (rusts, smuts, mildews, etc.). (See Nutrition of the Fungi, paragraph 185.) Some of these are not capable of development unless upon their host, and are called *obligate* parasites. Others can grow not only as parasites but at other times can also grow on dead organic matter, and are called *facultative* parasites, i.e. they can choose either a parasitic life or a saprophytic one.

179. Parasites among the seed plants.—*Cuscuta.*—There are, however, parasites among the seed plants; for example, the dodder (Cuscuta), para-

sitic on clover, and a great variety of other plants. There is food enough in the seed for the young plant to take root and develop a slender stem until it takes hold of its host. It then twines around the stem of its host sending wedge-shaped haustoria into the stem to obtain food. The part then in connection with the ground dies.

The haustoria of the dodder form a complete junction with the vascular bundles of its host so that through the vessels water and salts are obtained, while through the junction of sieve tubes the elaborated organic food is

Fig. 74.
Dodder.

obtained. The union of the dodder with its host is like that between a graft and the graft stock. The beech drops (Epiphegus) is another example of a parasitic seed plant. It is parasitic on the roots of the beech.

180. The mistletoe (Phoradendron), which grows on the branches of trees, sends its roots into the branches, and only the vessels of the vascular system are fused according to some. If this is true then it probably obtains only water and salts from its host. But the mistletoe has green leaves and is thus able to assimilate carbon dioxide and manufacture its own

organic substances. It is claimed by some, however, that the host derives some food from the parasite during the winter when the host has shed its leaves, and if this is true it would seem that organic food could also be derived during the summer from the host by the mistletoe.

181. Saprophytes.—A saprophyte is a plant which is enabled to obtain its food, especially its organic food, directly from dead animals or plants or from dead organic substances. Many fungi are saprophytes, as the moulds, mushrooms, etc. (See Nutrition of the Fungi.)

182. Humus saprophytes.—The action of fungi as described in the preceding chapter, as well as of certain bacteria, gradually converts the dead plants or plant parts into the finely powdered brown substance known as *humus*. In general the green plants cannot absorb organic food from humus directly. But plants which are devoid of chlorophyll can live saprophytically on this humus. They are known as *humus saprophytes*. Many of the mushrooms and other fungi, as well as some seed plants which lack chlorophyll or possess only a small quantity, are able to absorb all their organic food from humus. It is uncertain whether any seed plants can obtain all of their organic food directly from humus, though it is believed that many can so obtain a portion of it. But a number of seed plants, like the Indian pipe (Monotropa) and certain orchids, obtain organic food from humus. These plants lack chlorophyll and cannot therefore manufacture their own carbohydrate food. Not being parasitic on plants which can, as in the case of the dodder and beech drops mentioned above, they undoubtedly derive their organic food from the humus. But fungus mycelium growing in the humus is attached to their roots, and in some orchids enters the roots and forms a nutritive connection. The fungus mycelium can absorb organic food from the humus and in some cases at least can transfer it over to the roots of the higher plant (see Mycorhiza).

183. Autotrophic, heterotrophic, and mixotrophic plants.—An *autotrophic* plant is one which is self-nourishing, i.e. it is provided with an abundant chlorophyll apparatus for carbon dioxide assimilation and with absorbing organs for obtaining water and salts. Heterotrophic plants are not provided with a chlorophyll apparatus sufficient to assimilate all the carbon dioxide necessary, so they nourish themselves by other means. *Mixotrophic* plants are those which are intermediate between the other two, i.e. they have some chlorophyll but not enough to provide all the organic food necessary, so they obtain a portion of it by other means. Evidently there are all gradations of mixotrophic plants between the two other kinds (example, the mistletoe).

184. Symbiosis.—Symbiosis means a living with or living together, and is said of those organisms which live so closely in connection with each other as to be influenced for better or worse, especially from a nutrition standpoint. *Conjunctive* symbiosis has reference to those cases where

there is a direct interchange of food material between the two organisms (lichens, mycorhiza, etc.) *Disjunctive* symbiosis has reference to an inter life relation without any fixed union between them (example, the relations between flowers and insects, ants and plants, and even in a broad sense the relation between saprophytic plants in reducing organic matter to a condition in which it may be used for food by the green plants, and these in turn provide organic matter for the saprophytes to feed upon, etc.). *Antagonistic* symbiosis is shown in the relation of parasite to its host, *reciprocal* symbiosis, or *mutualistic* symbiosis is shown in those cases where both symbionts derive food as a result of the union (lichens, mycorhiza, etc.).

3. How Fungi Obtain their Food.

185. Nutrition of moulds.—In our study of mucor, as we have seen, the growing or vegetative part of the plant, the mycelium, lies within the substratum, which contains the food materials in solution, and the slender threads are thus bathed on all sides by them. The mycelium absorbs the watery solutions throughout the entire system of ramifications. When the upright fruiting threads are developed they derive the materials for their growth directly from the mycelium with which they are in connection. The moulds which grow on decaying fruit or on other organic matter derive their nutrient materials in the same way. The portion of the mould which we usually see on the surface of these substances is in general the fruiting part. The larger part of the mycelium lies hidden within the subtratum.

Fig. 75.
Carnation rust on leaf and flower stem. From photograph.

186. Nutrition of parasitic fungi.—Certain of the fungi grow on or within the higher plants and derive their food materials from them and at their expense. Such a fungus is called a *parasite*, and there are a large number

of these plants which are known as *parasitic fungi*. The plant at whose expense they grow is called the "*host*."

One of these parasitic fungi, which it is quite easy to obtain in greenhouses or conservatories during the autumn and winter, is the carnation rust (*Uromyces caryophyllinus*), since it breaks out in rusty dark brown patches on the leaves and stems of the carnation (see fig. 75). If we make thin cross sections through one of these spots on a leaf, and place them for a

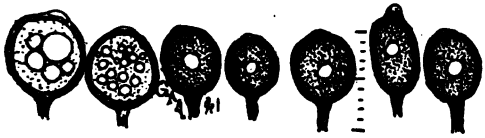

Fig. 76.
Several teleutospores, showing the variations in form.

few minutes in a solution of chloral hydrate, portions of the tissues of the leaf will be dissolved. After a few minutes we wash the sections in water on a glass slip, and stain them with a solution of eosin. If the sections were care-

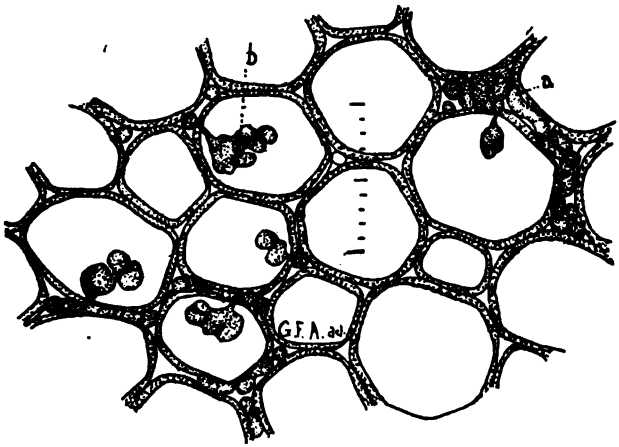

Fig. 77.
Cells from the stem of a rusted carnation, showing the intercellular mycelium and haustoria. Object magnified 30 times more than the scale.

fully made, and thin, the threads of the mycelium will be seen coursing between the cells of the leaf as slender threads. Here and there will be seen short branches of these threads which penetrate the cell wall of the host and project into the interior of the cell in the form of an irregular knob. Such a branch is a *haustorium*. By means of this haustorium, which is here

only a short branch of the mycelium, nutritive substances are taken by the fungus from the protoplasm or cell-sap of the carnation. From here it passes to the threads of the mycelium. These in turn supply food material for the development of the dark brown gonidia, which we see form the dark-looking powder on the spots. Many other fungi form haustoria, which take up nutrient matters in the way described for the carnation rust. In the case

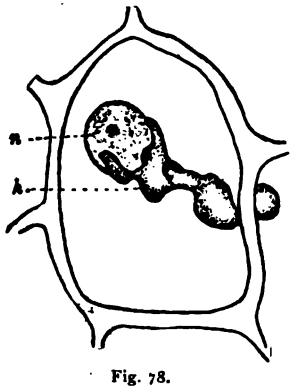

Fig. 78.

Cell from carnation leaf, showing haustorium of rust mycelium grasping the nucleus of the host. *h*, haustorium; *n*, nucleus of host.

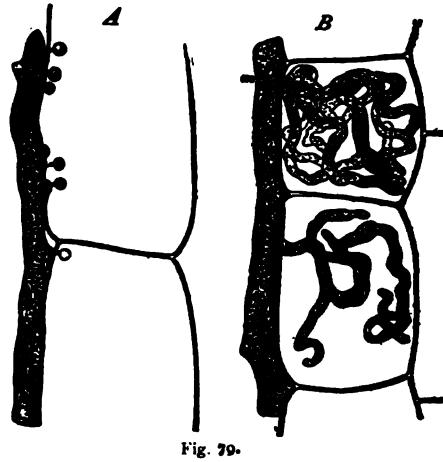

Fig. 79.

Intercellular mycelium with haustoria entering the cells. *A*, of Cystopus candidus (white rust); *B*, of Peronospora calotheca. (De Bary.)

of other parasitic fungi the threads of the mycelium themselves penetrate the cells of the host, while in still others the mycelium courses only between the cells of the host (fungus of peach leaf-curl for example) and derives food materials from the protoplasm or cell-sap of the host by the process of osmosis.

187. Nutrition of the larger fungi.—If we select some one of the larger fungi, the majority of which belong to the mushroom family and its relatives, which is growing on a decaying log or in the soil, we shall see on tearing open the log, or on removing the bark or part of the soil, as the case may be, that the stem of the plant, if it have one, is connected with whitish strands. During the spring, summer, or autumn months, examples of the mushrooms connected with these strands may usually be found readily in the fields or woods, but during the winter and

colder parts of the year often they may be seen in forcing houses, especially those cellars devoted to the propagation of the mushroom of commerce.

188. These strands are made up of numerous threads of the mycelium which are closely twisted and interwoven into a cord or strand, which is called a mycelium strand, or *rhizomorph.* These are well shown in fig. 236, which is from a photograph of the mycelium strands, or "spawn" as the grower of mushrooms calls it, of Agaricus campestris. The little knobs or enlargements on the strands are the young fruit bodies, or "buttons."

189. While these threads or strands of the mycelium in the decaying wood or in the decaying organic matter of the soil are

Fig. 80.

Sterile mycelium on wood props in coal mine, 400 feet below surface. (Photographed by the author.)

not true roots, they function as roots, or root hairs, in the absorption of food materials. In old cellars and on damp soil in moist places we sometimes see fine examples of this vegetative part of the fungi, the mycelium. But most magnificent examples are to be seen in abandoned mines where timber has been taken down into the tunnels far below the surface of the ground to support the rock roof above the mining operations. I have visited some of the coal mines at Wilkesbarre, Pa., and here on the wood props and doors, several hundred feet below the surface, and in blackest darkness, in an atmosphere almost completely saturated at all times, the mycelium of some of the wood-destroying fungi grows in a profusion and magnificence which is almost beyond belief. Fig. 80 is from a flash-light photograph of a beautiful example 400 feet below the surface of the ground. This was growing over the surface of a wood prop or post, and the picture is much reduced. On the doors in the mine one can see the strands of the mycelium which radiate in fan-like figures at certain places near the margin of growth, and farther back the delicate tassels of mycelium which hang down in fantastic figures, all in spotless white and rivalling the most beautiful fabric in the exquisiteness of its construction.

190. How fungi derive carbohydrate food.—The fungi being devoid of chlorophyll cannot assimilate the CO_2 from the air. They are therefore dependent on the green plants for their carbohydrate food. Among the saprophytes, the leaf and wood destroying fungi excrete certain substances (known as *enzymes*) which dissolve the carbohydrates and certain other organic compounds in the woody or leafy substratum in which they grow. They thus produce a sort of extracellular digestion of carbohydrates, converting them into a soluble form which can be absorbed by the mycelium. The parasitic fungi also obtain their carbohydrates and other organic food from the host. The mycelium of certain parasitic, and of wood destroying fungi, excretes enzymes (*cytase*) which dissolve minute perforations in the cell walls of the host and thus aid the hypha during its boring action in penetrating cell walls.

NOTE.—Certain wood destroying fungi growing in oaks absorb tannin directly, i.e. in an unchanged form. One of the pine destroying fungi (*Trametes pini*) absorbs the xylogen from the wood cells, leaving the pure cellulose in which the xylogen was filtrated; while *Polyporus mollis* absorbs the cellulose, leaving behind only the wood element.

4. Mycorhiza.

191. While such plants as the Indian pipe (Monotropa), some of the orchids, etc., are *humus saprophytes* and some of them are possibly able to absorb organic food from the humus, many of them have fungus mycelium in close connection with their roots, and these fungus threads aid in the absorption of organic food. The roots of plants which have fungus mycelium intimately associated in connection with the process of nutrition, are termed *mycorhiza*. There is a mutual interchange of food between the fungus and the host, a *reciprocal symbiosis*.

192. Mycorhiza are of two kinds as regards the relation of the fungus to the root; *ectotrophic* (or *epiphytic*), where the mycelium is chiefly on the outside of the root, and *endotrophic* (or *endophytic*) where the mycelium is chiefly within the tissue of the root.

193. Ectotrophic mycorhiza.—Ectotrophic mycorhiza occur on the roots of the oak, beech, hornbean, etc., in forests where there is a great deal of humus from decaying leaves and other vegetation. The young growing roots of these trees become closely covered with a thick felt of the mycelium, so that no root hairs can develop. The terminal roots also branch profusely and are considerably thickened. The fungus serves here as the absorbent organ for the tree. It also acts on the humus, converting some of it into available plant food and transferring it over to the tree.

194. Endotrophic mycorhiza.—These are found on many of the humus saprophytes, which are devoid of chlorophyll, as well as on those possessing little or even on some plants possessing an abundance, of chlorophyll. Examples are found in many orchids (see the coral root orchid, for example), some of the ferns (Botrychium), the pines, leguminous plants, etc. In endotrophic mycorhiza the mycelium is more abundant within the tissues of the root, though some of the threads extend to the outside. In the case of the mycorhiza on the humus saprophytes which have no chlorophyll, or but little, it is thought by some that the fungus mycelium in the humus assists in converting organic substances and carbohydrates into a form available for food by the higher plant and then conducts it into the root, thus aiding also in the process of absorption, since there are few or no root hairs on the short and fleshy mycorhiza. The roots, however, of some of these humus saprophytes have the power of absorbing a portion of their organic compounds from the humus. It is thought by some, though not definitely demonstrated, that in the case of the oaks, beeches, hornbeans, and other chlorophyll-bearing symbionts, the fungus threads do not absorb any carbohydrates for the higher symbiont, but that they actually derive their carbohydrates from it.* But it is reasonably certain that the fungus

* Evidence points to the belief that certain cells of the host form substances which attract, chemitropically, the fungus threads, and that in these cells the fungus threads are more abundant than in others. Furthermore in the vicinity of the nucleus of the host seems to be the place where these activities are more marked.

threads do assimilate from the humus certain unoxidized, or feebly oxidized, nitrogenous substances (ammonia, for example), and transfer them over to the host, for the higher plants with difficulty absorb these substances, while they readily absorb nitrates which are not abundant in humus. This is especially important in the forest. It is likely therefore that the fungus symbiont supplies nitrogen to its host, though it does not assimilate free nitrogen as is the case in the following examples.

5. Nitrogen gatherers.

195. How clovers, peas, and other legumes gather nitrogen.—It has long been known that clover plants, peas, beans, and many other leguminous plants are often able to thrive in soil where the cereals do but poorly. Soil poor in nitrogenous plant food becomes richer in this substance where clovers, peas, etc., are grown, and they are often planted for the purpose of enriching the soil. Leguminous plants, especially in poor soil, are almost certain to have enlargements, in the form of nodules, or "root tubercles." A root of the common vetch with some of these root tubercles is shown in fig. 81.

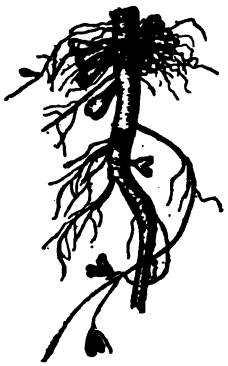

Fig. 81.
Root of the common vetch, showing root tubercles.

196. A fungal or bacterial organism in these root tubercles.—If we cut one of these root tubercles open, and mount a small portion of the interior in water for examination with the microscope, we shall find small rod-shaped bodies, some of which resemble bacteria, while others are more or less forked into forms like the letter Y, as shown in fig. 82. These bodies are rich in nitrogenous substances, or proteids. They are portions of a minute organism, of a fungus or bacterial nature, which attacks the roots of leguminous plants

Fig. 82.
Root-tubercle organism from vetch, old condition.

Fig. 83.
Root-tubercle organism from Medicago denticulata.

and causes these nodular outgrowths. The organism (Phytomyxa leguminosarum) exists in the soil and is widely distributed where legumes grow.

197. How the organism gets into the roots of the legumes.—This minute organism in the soil makes its way through the wall of a root hair near the end. It then grows down the interior of the root hair in the form of a thread. When it reaches the cell walls it makes a minute perforation, through which it grows to enter the adjacent cell, when it enlarges again. In this way it passes from the root hair to the cells of the root and down to near the center of the root. As soon as it begins to enter the cells of the root it stimulates the cells of that portion to greater activity. So the root here develops a large lateral nodule, or "root tubercle." As this "root tubercle" increases in size, the fungus threads branch in all directions, entering many cells. The threads are very irregular in form, and from certain enlargements it appears that the rod-like bodies are formed, or the thread later breaks into myriads of these small "bacteroids."

198. The root organism assimilates free nitrogen for its host.—This organism assimilates the free nitrogen from the air in the soil, to make the proteid substance which is found stored in the bacteroids in large quantities. Some of the bacteroids, rich in proteids, are dissolved, and the proteid substance is made use of by the clover or pea, as the case may be. This is why such plants can thrive in soil with a poor nitrogen content. Later in the season some of the root tubercles die and decay. In this way some of the proteid substance is set free in the soil. The soil thus becomes richer in nitrogenous plant food.

The forms of the bacteroids vary. In some of the clovers they are oval, in vetch they are rod-like or forked, and other forms occur in some of the other genera.

199. NOTE.—So far as we know the legume tubercle organism does not assimilate free nitrogen of the air unless it is within the root of the legume. But there are microörganisms in the soil which are capable of assimilating free nitrogen independently. Example, a bacterium, *Clostridium pasteurianum*. Certain bacteria and algæ live in *contact symbiosis* in the soil, the bacteria fixing free nitrogen, while in return for the combined nitrogen, the algæ furnish the bacteria with carbohydrates. It seems that these bacteria cannot fix the free nitrogen of the air unless they are supplied with carbohydrates, and it is known that *Clostridium pasteurianum* cannot assimilate free nitrogen unless sugar is present.

6. Lichens.

200. Nutrition of lichens.—Lichens are very curious plants which grow on rocks, on the trunks and branches of trees, and on the soil. They form leaf-like expansions more or less green in color, or brownish, or gray, or they occur in the form of threads, or small tree-like formations. Sometimes the

plant fits so closely to the rock on which it grows that it seems merely to paint the rock a slightly different color, and in the case of many which occur on trees there appears to be to the eye only a very slight discoloration of the bark of the trunk, with here and there the darker colored points where fruit bodies

Fig. 84.
Frond of lichen (peltigera), showing rhizoids.

are formed. The most curious thing about them is, however, that while they form plant bodies of various form, these bodies are of a "dual nature" as regards the organisms composing them. The plant bodies, in other words, are formed of two different organisms which, woven together, exist apparently as one. A fungus on the one hand grows around and encloses in the meshes of its mycelium the cells or threads of an alga, as the case may be.

If we take one of the leaf-like forms known as peltigera, which grows on damp soil or on the surfaces of badly decayed logs, we see that the plant body is flattened, thin, crumpled, and irregularly lobed. The color is dull greenish on the upper side, while the under side is white or light gray, and mottled with brown, especially the older portions. Here and there on the under surface are quite long slender blackish strands. These are composed entirely of fungus threads and serve as organs of attachment or holdfasts, and for the purpose of supplying the plant body with mineral substances which are in solution in the water of the soil. If we make a thin section of the leaf-like portion of a lichen as shown in fig. 85, we shall see that it is composed of a mesh of colorless threads which in certain definite portions contain entangled green cells. The colorless threads are those of the fungus, while the green cells are those of the alga. These green cells of the alga perform the function of chlorophyll bodies for the dual organism, while the threads of the fungus provide the mineral constituents of plant food. The alga,

while it is not killed in the embrace of the fungus, does not reach the perfect state of development which it attains when not in connection with the fungus. On the other hand the fungus profits more than the alga by this association. It forms fruit bodies, and perfects spores in the special fruit bodies, which are so very distinct in the case of so many of the species of the lichens. These plants have lived for so long a time in this close association that the fungi are rarely found separate from the algæ in nature, but in a number of cases they have been induced to grow in artificial cultures sep-

Fig. 85.

Lichen (peltigera), section of thallus; dark zone of rounded bodies made up largely of the algal cells. Fungus cells above, and threads beneath and among the algal cells.

arate from the alga. This fact, and also the fact that the algæ are often found to occur separate from the fungus in nature, is regarded by many as an indication that the plant body of the lichens is composed of two distinct organisms, and that the fungus is parasitic on the alga.

201. Others regard the lichens as autonomous plants, that is, the two organisms have by this long-continued community of existence become unified into an individualized organism, which possesses a habit and mode of life

distinct from that of either of the organisms forming the component parts. This community of existence between two different organisms is called by some *mutualism*, or *symbiosis*. While the alga inclosed within the meshes of the fungus is not so free to develop, and probably does not attain the full development which it would alone under favorable conditions, still it is

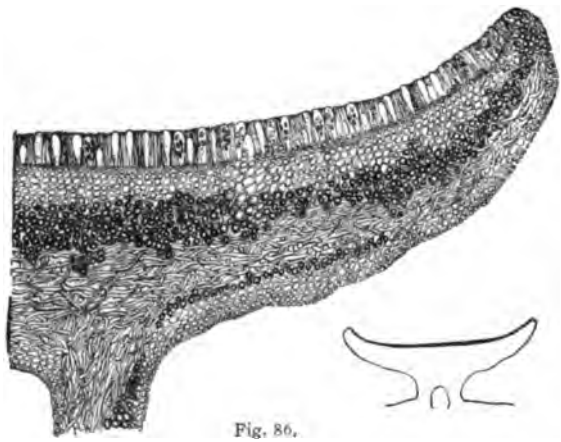

Fig. 86.

Section of fruit body or apothecium of lichen (parmelia), showing asci and spores of the fungus.

very likely that it is often preserved from destruction during very dry periods, within the tough thallus, on the surface of bare rocks.

CHAPTER X.

HOW PLANTS OBTAIN THEIR FOOD, II.

Seedlings.

202. It is evident from some of the studies which we have made in connection with germination of seeds and nutrition of the plant that there is a period in the life of the seed plants in which they are able to grow if supplied with moisture, but may entirely lack any supply of food substance from the outside, though we understand that growth finally comes to a standstill unless they are supplied with food from the outside. In connection with the study of the nutrition of the plant, therefore, it will be well to study some of the representative seeds and seedlings to learn more accurately the method of germination and nutrition in seedlings during the germinating period.

203. To prepare seeds for germination.—Soak a handful of seeds (or more if the class is large) in water for 12 to 24 hours. Take shallow crockery plates, or ordinary plates, or a germinator with a fluted bottom. Place in the bottom some sheets of paper, and if sphagnum moss is at hand scatter some over the paper. If the moss is not at hand, throw the upper layer of paper into numerous folds. Thoroughly wet the paper and moss, but do not have an excess of water. Scatter the seeds among the moss or the folds of the paper. Cover with some more wet paper and keep in a room where the temperature is about 20° C. to 25° C. The germinator should be looked after to see that the paper does not become dry. It may be necessary to cover it with another vessel to prevent the too rapid evaporation of the water. The germinator should be started about a week before the seedlings are wanted for study. Some of the soaked seeds should be planted in soil in pots and kept at the same temperature, for comparison with those grown in the germinator.

204. Structure of the grain of corn.—Take grains of corn that have been

soaked in water for 24 hours and note the form and difference in the two sides (in all of these studies the form and structure of the seed, as well as the stages in germination, should be illustrated by the student). Make a longisection of a grain of corn through the middle line, if necessary making several in order to obtain one which shows the structures well near the smaller end of the grain. Note the following structures: 1st, the hard outer "wall" (formed of the consolidated wall of the ovary with the integuments of the ovules—see Chapters 35 and 36); 2d, the greater mass of starch and other plant food (the endosperm) in the centre; 3d, a somewhat crescent-shaped body (the *scutellum*) lying next the endosperm and near the smaller end of the grain; 4th, the remaining portion of the young embryo lying between the scutellum and the seed coat in the depression. When good sections are made one can make out the radicle at the smaller end of the seed, and a few successive leaves (the plumule) which lie at the opposite end of the embryo shown by sharply curved parallel lines. Observe the attachment of the scutellum to the caulicle at the point of junction of the plumule and the radicle. The scutellum is a part of the embryo and represents a cotyledon. The endosperm is also called *albumen*, and such a seed is *albuminous*.

Fig. 87.

Section of corn seed; at upper right of each is the plantlet, next the cotyledon, at left the endosperm.

Dissect out an embryo from another seed, and compare with that seen in the section.

205. In the germination of the grain of corn the endosperm supplies the food for the growth of the embryo until the roots are well established in the soil and the leaves have become expanded and green, in which stage the plant has become able to obtain its food from the soil and air and live independently. The starch in the endosperm cannot of course be used for food by the embryo in the form of starch. It is first converted into a soluble form and then absorbed through the surface of the scutellum or cotyledon and carried to all parts of the embryo. An enzyme developed by the embryo acts upon the starch, converting it into a form of sugar which is in solution and can thus be absorbed. This enzyme is one of the so-called diastatic "ferments" which are formed during the germination of all seeds which contain food stored in the form of starch. In some seedlings, this diastase formed is developed in much greater abundance than in others, for example, in barley. Examine grains of corn still attached to seedlings several weeks old and note that a large part of their content has been used up. The action of diastase on starch is described in Chapter 8.

206. Structure of the pumpkin seed.—The pumpkin seed has a tough papery outer covering for the protection of the embryo plant within. This covering is made up of the seed coats. When the seed is opened by slitting off these coats there is seen within the "meat" of the pumpkin seed. This is nothing more than the embryo plant. The larger part of this embryo consists of two flattened bodies which are more prominent than any other part of the plantlet at this time. These two flattened bodies are the two first leaves, usually called *cotyledons*. If we spread these cotyledons apart we see that they are connected at one end. Lying between them at this point of attachment is a small bud. This is the *plumule*. The plumule consists of the very young leaves at the end of the stem which will grow as the seed germinates. At the other end where the cotyledons are joined is a small projection, the young root, often termed the *radicle*.

207. How the embryo gets out of a pumpkin seed.—To see how the embryo gets out of the pumpkin seed we should examine seeds germinated in the folds of damp paper or on damp sphagnum, as well as some which have been germinated in earth. Seeds should be selected which represent several different stages of germination.

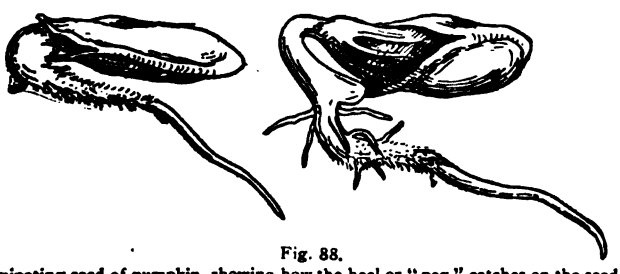

Fig. 88.

Germinating seed of pumpkin, showing how the heel or "peg" catches on the seed coat to cast it off.

208. The peg helps to pull the seed coats apart.—The root pushes its way out from between the stout seed coats at the smaller end, and then turns downward unless prevented from so

doing by a hard surface. After the root is 2–4*cm* long, and the two halves of the seed coats have begun to be pried apart, if we look in this rift at the junction of the root and stem, we shall see that one end of the seed coat is caught against a heel, or "peg," which has grown out from the stem for this purpose. Now if we examine one which is a little more advanced, we shall see this heel more distinctly, and also that the stem is arching out away from the seed coats. As the stem arches up its back in this way it pries with the cotyledons against the upper seed coat, but the lower seed coat is caught against this heel, and the two are pulled gradually apart. In this way the embryo plant pulls itself out from between the seed coats. In the case of seeds which are planted deeply in the soil we do not see this contrivance unless we dig down into the earth. The stem of the seedling arches through the soil, pulling the cotyledons up at one end. Then it straightens up, the green cotyledons part, and open out their inner faces to the sunlight, as shown in fig. 90. If we dig into the soil we shall see that this same heel is formed on the stem, and that the seed coats are cast off into the soil.

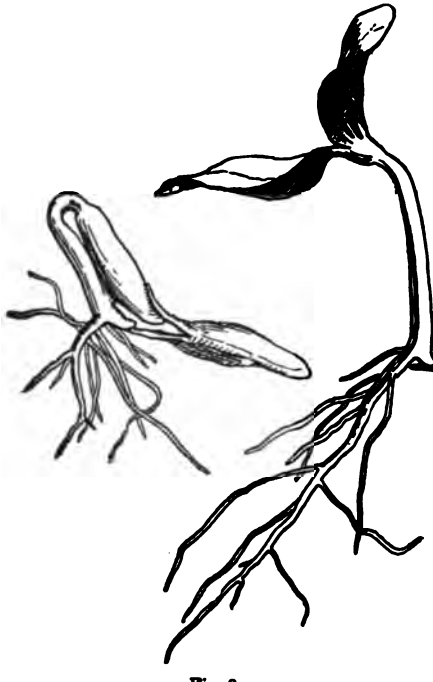

Fig. 89.
Escape of the pumpkin seedling from the seed coats.

209. Parts of the pumpkin seedling.—During the germination of the seed all parts of the embryo have enlarged. This increase in size of a plant is one of the peculiarities of growth. The cotyledons have elongated and expanded somewhat, though not to such a great extent as the root and the stem. The cotyledons also have become green on exposure to the light. Very soon after the main root has emerged from the seed coats, other lateral roots begin to form, so that the root soon becomes very much branched. The main root with its branches makes up the root system of the seedling. Between the expanded cotyledons is seen the plumule. This has enlarged somewhat, but not nearly so much as the root, or the part of the stem which extends below the cotyledons. This part of the stem, i.e., that part below the cotyledons and extending to the beginning of the root, is called in all seedlings the *hypocotyl*, which means "below the cotyledon."

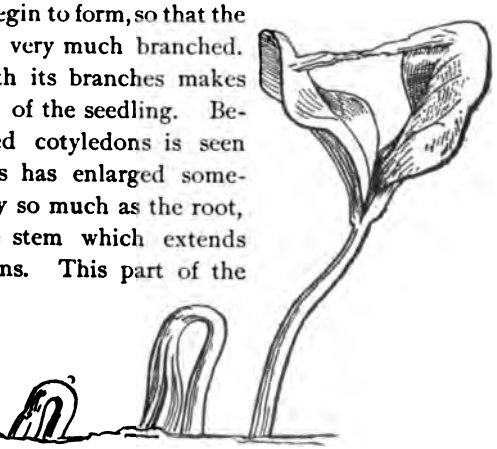

Fig. 90.
Pumpkin seedling rising from the ground.

210. The common garden bean.—The common garden bean or the lima bean, may be used for study. The garden bean is not so flattened or broadened as the lima bean. It is rounded-compressed, elongate slightly curved, slightly concave on one side and convex on the other, and the ends are rounded. At the middle of the concave side note the distinct scar (the hilum) formed where the bean seed separates from its attachment to the wall of the pod. Upon one side of this scar is a slight prominence which is continued for a short distance toward the end of the bean in the form of a slight ridge. This is the *raphe*, and represents that part of the stalk of the ovule which is joined to the side of the ovule when the latter is curved around against it

(see Chapter 36), and at the outer end of the raphe is the *chalaza*, the point where the stalk is joined to the end of the ovule, best understood in a straight ovule Upon the opposite side of the scar and close to it can be seen a minute depression, the *micropyle*. Underneath the seed coat and lying between this point and the end of the seed is the *embryo*, which gives greater prominence to the bean at this point, but it is especially more prominent after the bean has been soaked in water. Soak the beans in water and as they are swelling note how the seed coats swell faster than the inner portion of the seed, which causes them to wrinkle in a curious way, but finally the inner portion swells and fills the seed coat out smooth again. Sketch a bean showing all the external features both in side view and in front. Split one lengthwise and sketch the half to which the embryo clings, noting the young root, stem, and the small leaves which were lying between the cotyledons. There is no endosperm here now, since it was all used up in the growth of the embryo, and a large part of its substance was stored up in the cotyledons. As the seed germinates the young plant gets its first food from that stored in the cotyledons. The hypocotyl elongates, becomes strongly arched, and at last straightens up, lifting the cotyledons from the soil. As the cotyledons become exposed to the light they assume a green color. Some of the stored food in them goes to nourish the embryo during germination, and they therefore become smaller, shrivel somewhat, and at last fall off.

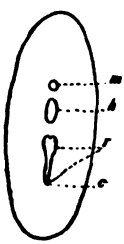

Fig. 91.
Garden bean. *m*, micropyle; *h*, hilum or scar; *r*, raphe; *c*, point where chalaza lies.

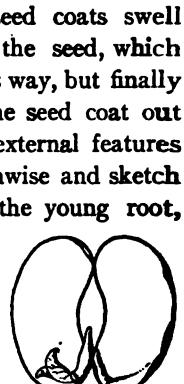

Fig. 92.
Bean seed split open to show plantlet.

211. The castor-oil bean.—This is not a true bean, since it belongs to a very different family of plants (Euphorbiaceæ). In the germination of this seed a very interesting comparison can be made with that of the garden bean. As the "bean" swells the very hard outer coat generally breaks open at the free end and slips off at the stem end. The next coat within, which is

also hard and shining black, splits open at the opposite end, that is at the stem end. It usually splits open in the form of three ribs. Next within the inner coat is a very thin, whitish film (the remains of the nucellus, and corresponding to the perisperm) which shrivels up and loosens from the white mass, the endosperm, within. In the castor-oil bean, then, the endosperm is not all absorbed by the embryo during the formation of the seed. As the plant becomes older we should note that the fleshy endosperm becomes thinner and thinner, and at last there is nothing but a thin, whitish film covering the green faces of the cotyledons. The endosperm has been gradually absorbed by the germinating plant through its cotyledons and used for food.

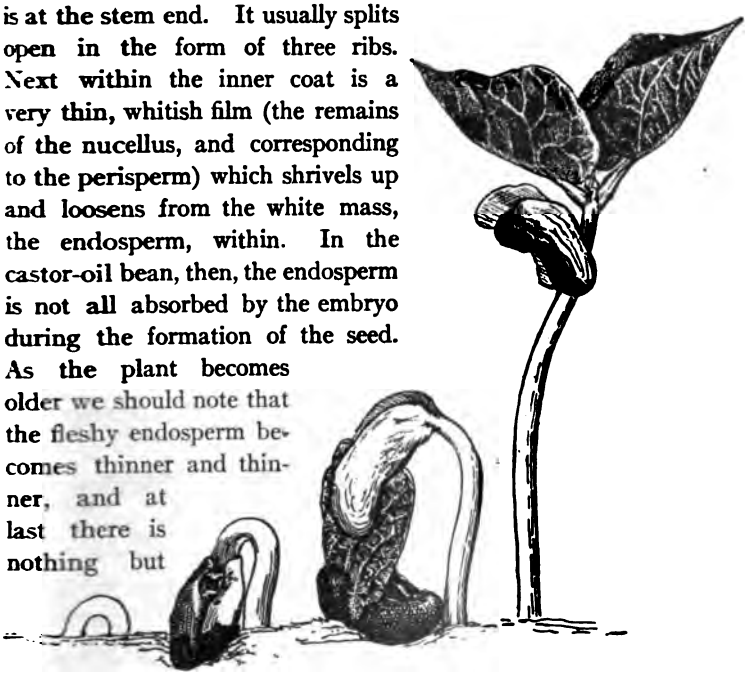

Fig. 93.

How the garden bean comes out of the ground. First the looped hypocotyl, then the cotyledons pulled out, next casting off the seed coat, last the plant erect, bearing thick cotyledons, the expanding leaves, and the plumule between them.

Arisæma triphyllum.*

212. Germination of seeds of jack-in-the-pulpit.—The ovaries of jack-in-the-pulpit form large, bright red berries with a soft pulp enclosing one to several large seeds. The seeds are oval in form. Their germination is interesting, and illustrates one type

* In lieu of Arisæma make a practical study of the pea. See paragraph 216a.

of germination of seeds common among monocotyledonous plants. If the seeds are covered with sand, and kept in a moist place, they will germinate readily.

213. How the embryo backs out of the seed.—The embryo lies within the mass of the endosperm; the root end, near the smaller end of the seed. The club-shaped cotyledon lies near the

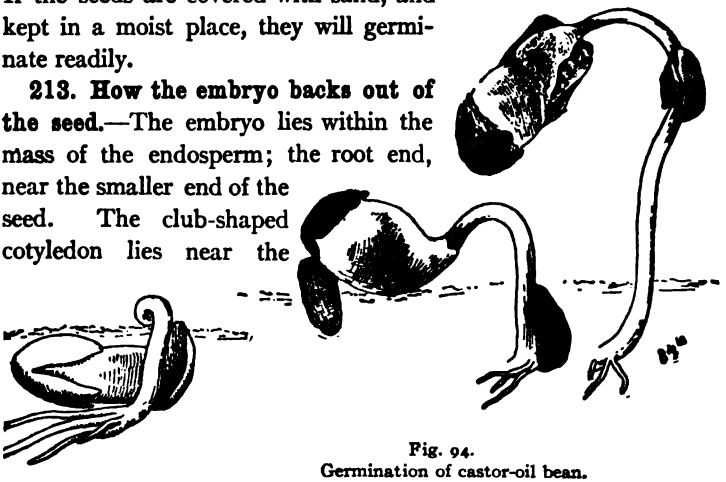

Fig. 94.
Germination of castor-oil bean.

middle of the seed, surrounded firmly on all sides by the endosperm. The stalk, or petiole, of the cotyledon, like the lower part of the petiole of the leaves, is a hollow cylinder, and contains the younger leaves, and the growing end of the stem or bud. When germination begins, the stalk, or petiole, of the cotyledon elongates. This pushes the root end of the embryo out at the small end of the seed. The free end of the embryo now enlarges somewhat, as seen in the figures, and becomes the bulb, or corm, of the young plant. At first no roots are visible, but in a short time one, two, or more roots appear on the enlarged end.

214. Section of an embryo.—If we make a longisection of the embryo and seed at this time we can see how the club-shaped cotyledon is closely surrounded by the endosperm. Through the cotyledon, then, the nourishment from the endosperm is readily passed over to the growing embryo. In the hollow part of the petiole near the bulb can be seen the first leaf.

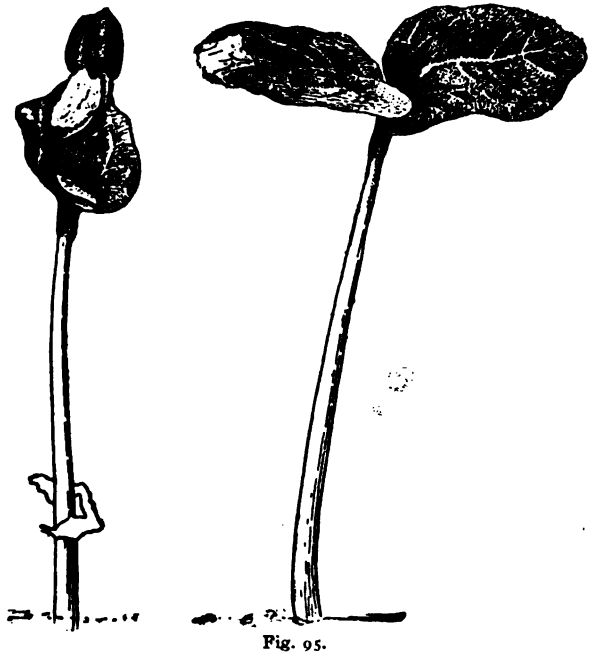

Fig. 95.

Seedlings of castor-oil bean casting the seed coats, and showing papery remnant of the endosperm.

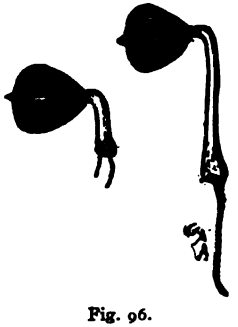

Fig. 96.

Seedlings of jack-in-the-pulpit; embryo backing out of the seed.

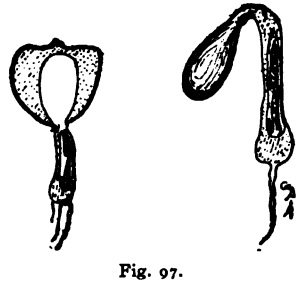

Fig. 97.

Section of germinating embryos of jack-in-the-pulpit, showing young leaves inside the petiole of the cotyledon. At the left cotyledon shown surrounded by the endosperm in the seed; at right endosperm removed to show the club-shaped cotyledon.

215. How the first leaf appears.—As the embryo backs out of the seed, it turns downward into the soil, unless the seed is so lying that it pushes straight downward. On the upper side of the arch thus formed, in the petiole of the cotyledon, a slit appears, and through this opening the first leaf arches its way out. The loop of the petiole comes out first, and the leaf later, as shown in fig. 98. The petiole now gradually straightens up, and as it elongates the leaf expands.

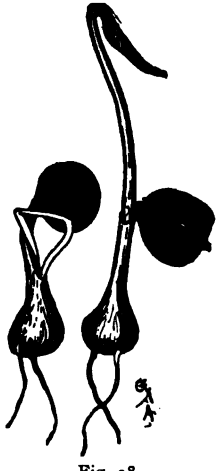

Fig. 98.
Seedlings of jack-in-the-pulpit, first leaf arching out of the petiole of the cotyledon.

Fig. 99.
Embryos of jack-in-the-pulpit still attached to the endosperm in seed coats, and showing the simple first leaf.

Fig. 100.
Seedling of jack-in-the-pulpit; section of the endosperm and cotyledon.

216. The first leaf of the jack-in-the-pulpit is a simple one.—The first leaf of the embryo jack-in-the-pulpit is very different in form from the leaves which we are accustomed to see on mature plants. If we did not know that it came from the seed

of this plant we would not recognize it. It is simple, that is it consists of one lamina or blade, and not of three leaflets as in the compound leaf of the mature plant. The simple leaf is ovate and with a broad heart-shaped base. The jack-in-the-pulpit, then, as trillium, and some other monocotyledonous plants which have compound leaves on the mature plants, have simple leaves during embryonic development. The ancestral monocotyledons are supposed to have had simple leaves. Thus there is in the embryonic development of the jack-in-the-pulpit, and others with compound leaves; a sort of recapitulation of the evolutionary history of the leaf in these forms.

216*a*. Germination of the pea.—Compare with the bean. Note especially that the cotyledons are not lifted above the soil as in the beans. Compare germination of acorns.

Digestion.

216*b*. To test for food substance in the seedlings studied.—The pumpkin, squash, and castor-oil bean are examples of what are called oily seeds, though flaxseed, cotton-seed, and nuts are better. Remove a small portion of the substance from the cotyledon of the squash and crush it on a glass slip in a drop or two of osmic acid.* Put on a cover-glass and examine with the microscope. The black amorphous matter shows the presence of oil in the protoplasm. The small bodies which are stained yellow are aleurone grains, a form of protein or albuminous substance. Make sections of the meat of a Brazil nut or hickory nut and immerse for several hours in osmic acid. They become black because of the quantity of oil. Mount in water and examine under the microscope. The oil is in globules which are colored black. The oil is converted into an available food form by the action of an enzyme called *lipase*, which splits up the fatty oil into glucose and other substances. Lipase has been found in the endosperm of the castor bean, cocoanut, and in the cotyledons of the pumpkin, as well as in other seeds containing oil as a stored product. The aleurone is made available by an enzyme of the nature of trypsin.

Test the cotyledon of the bean with iodine for the presence of starch. If the endosperm of corn seed has not been tested do so now w th iodine. The endosperm consists largely of starch. The starch is converted to glu-

* Dissolve a half gram of osmic acid in 50 cc. of water and keep tightly corked when not using.

cose by a diastatic "ferment" formed by the seedling as it germinates. Make a thin cross-section of a grain of wheat, including the seed coat and a portion of the interior, treat with iodine and mount for microscopic examination. Note the abundance of starch in the internal portion of endosperm. Note a layer of cells on the outside of the starch portions filled with small bodies which stain yellow. These are aleurone grains. The cellulose in the cell walls of the endosperm is dissolved by another enzyme called *cytase*, and some plants store up cellulose for food. For example, in the endosperm of the *date* the cell walls are very much thickened and pitted. The cell walls consist of reserve cellulose and the seedling makes use of it for food during growth.

216*c*. Albuminous and exalbuminous seeds.—In seeds where the food is stored outside of the embryo they are called *albuminous;* examples, corn, wheat and other cereals, Indian turnip, etc. In those seeds where the food is stored up in the embryo they are called *exalbuminous;* examples, bean, pea, pumpkin, squash, etc.

217. Digestion has a well-defined meaning in animal physiology and relates to the conversion of solid food, usually within the stomach, into a soluble form by the action of certain gastric juices, so that the liquid food may be absorbed into the circulatory system. The term is not often applied in plant physiology, since the method of obtaining food is in general fundamentally different in plants and animals. It is usually applied to the process of the conversion of starch into some form of sugar in solution, as glucose, etc. This we have found takes place in the leaf, especially at night, through the action of a diastatic ferment developed more abundantly in darkness. As a result, the starch formed during the day in the leaves is digested at night and converted into sugar, in which form it is transferred to the growing parts to be employed in the making of new tissues, or it is stored for future use; in other cases it unites with certain inorganic substances, absorbed by the roots and raised to the leaf, to form proteids and other organic substances. In tubers, seeds, parts of stems or leaves where starch is stored, it must first be "digested" by the action of some enzyme before it can be used as food by the sprouting tubers or germinating seeds.

For example, starch is converted to a glucose by the action of a diastase. Cellulose is converted to a glucose by cytase. Albuminoids are converted into available food by a tryptic ferment. Fatty oils are converted into glucose and other products by lipase.

Inulin, a carbohydrate closely related to starch, is stored up for food in solution in many composite plants, as in the artichoke, the root tuber of dahlia, etc. When used for food by the growing plant it is converted into glucose by an enzyme, inulase. Make a section of a portion of a dahlia root and immerse in 95% alcohol for several hours. The inulin is precipitated into sphæro crystals. (See also paragraphs 156–161 and 216*b*.)

218. Then there are certain fungi which feed on starch or other organic substances whether in the host or not, which excrete certain enzymes to dissolve the starch, etc., to bring it into a soluble form before they can absorb it as food. Such a process is a sort of *extracellular digestion*, i.e., the organism excretes the enzyme and digests the solid outside, since it cannot take the food within its cells in the solid form. To a certain degree the higher plants perform also extracellular digestion in the action of root-hair excretion on insoluble substances, and in the case of the humus saprophytes. But for them soluble food is largely prepared by the action of acids, etc., in the soil or water, or by the work of fungi and bacteria as described in Chapter 9.

219. Assimilation.—In plant physiology the term assimilation has been chiefly used for the process of carbon-dioxide assimilation (= photosynthesis). Some objections have been raised against the use of assimilation here as one of the life processes of the plant, since its inception stages are due to the combined action of light, an external factor, and chlorophyll in the plant along with the living chloroplastid. So long, however, as it is not known that this process can take place without the aid of the living plant, it does not seem proper to deny that it is altogether not a process of assimilation. It is not necessary to restrict the term assimilation to the formation of new living matter in the plant cell; it can be applied also to the synthetic processes in the formation of carbohydrates, proteids, etc., and called synthetic assimilation. The sun supplies the energy, which is absorbed by the chlorophyll, for splitting up the carbonic acid, and the living chloroplast then assimilates by a synthetic process the carbon, hydrogen, and oxygen. This process then can be called *photosynthetic assimilation*. The nitrite and nitrate bacteria derive energy in the process of nitrification, which enables them to assimilate CO_2 from the air, and this is called *chemosynthetic assimilation*. The inorganic material in the form of mineral salts, nitrates, etc., absorbed by the root, and carried up to the leaves, here meets with the carbohydrates manufactured in the leaf. Under the influence of the protoplasm synthesis takes place, and proteids and other organic compounds are built up by the union of the salts, nitrates, etc., with the carbohydrates. This is also a process of synthetic assimilation. These are afterward stored as food, or assimilated by the protoplasm in the making of new living matter, or perhaps without the first process of synthetic assimilation some of the inorganic salts, nitrates, and carbohydrates meeting in the protoplasm are assimilated into new living matter directly.

CHAPTER XI.

RESPIRATION.

220. One of the life processes in plants which is extremely interesting, and which is exactly the same as one of the life processes of animals, is easily demonstrated in several ways.

221. Simple experiment to demonstrate the evolution of CO_2 during germination.—Where there are a number of students and a number of large cylinders are not at hand, take bottles of a pint capacity and place in the bottom some peas soaked for 12 to 24 hours. Cover with a glass plate which has been smeared with vaseline to make a tight joint with the mouth of the bottle. Set aside in a warm place for 24 hours. Then slide the glass plate a little to one side and quickly pour in a little baryta water so that it will run down on the inside of the bottle. Cover the bottle again. Note the precipitate of barium carbonate which demonstrates the presence of CO_2 in the bottle. Lower a lighted taper. It is extinguished because of the great quantity of CO_2. If flower buds are accessible, place a small handful in each of several jars and treat the same as in the case of the peas. Young growing mushrooms are excellent also for this experiment, and serve to show that respiration takes place in the fungi.

Fig. 101.
Test for presence of carbon dioxide in vessel with germinating peas. (Sachs.)

222. If we now take some of the baryta water and blow our "breath" upon it the same film will be formed. The carbon dioxide which we exhale is absorbed by the baryta water, and forms barium carbonate, just as in the case of the peas. In the case of animals the process by which oxygen is taken into the body and carbon dioxide is given off is *respiration.* The process in plants which we are now studying is the same, and also is respiration. The oxygen in the vessel was partly used up in the process, and carbon dioxide was given off. (It will be seen that this process is exactly the opposite of that which takes place in carbon-dioxide assimilation.)

223. To show that oxygen from the air is used up while plants respire.—Soak some wheat for 24 hours in water. Remove it from the water and place it in the folds of damp cloth or paper in a moist vessel. Let it remain until it begins to germinate. Fill the bulb of a thistle tube with the germinating wheat. By the aid of a stand and clamp, support the tube upright, as shown in fig. 102. Let the small end of the tube rest in a strong solution of caustic potash (one stick caustic potash in two-thirds tumbler of water) to which red ink has been added to give a deep red color. Place a small glass plate over the rim of the bulb and seal it air-tight with an abundance of vaseline. Two tubes can be set up in one vessel, or a second one can be set up in strong baryta water colored in the same way.

Fig. 102.

Apparatus to show respiration of germinating wheat.

224. The result.—It will be seen that the solution of caustic potash rises slowly in the tube; the baryta water will also, if that is used. The solution is colored so that it can be plainl··

seen at some distance from the table as it rises in the tube. In the experiment from which the figure was made for the accompanying illustration, the solution had risen in 6 hours to the height shown in fig. 102. In 24 hours it had risen to the height shown in fig. 103.

Fig. 103.
Apparatus to show respiration of germinating wheat.

225. Why the solution of caustic potash rises in the tube.—Since no air can get into the thistle tube from above or below, it must be that some part of the air which is inside of the tube is used up while the wheat is germinating. From our study of germinating peas, we know that a suffocating gas, carbon dioxide, is given off while respiration takes place. The caustic potash solution, or the baryta water, whichever is used, absorbs the carbon dioxide. The carbon dioxide is heavier than air, and so it settles down in the tube where it can be absorbed.

226. Where does the carbon dioxide come from?—We know it comes from the growing seedlings. The symbol for carbon dioxide is CO_2. The carbon comes from the plant, because there is not enough in the air. Nitrogen could not join with the carbon to make CO_2. Some oxygen from the air or from the protoplasm of the growing seedlings (more probably the latter) joins with some of the carbon of the plant. These break away from their association with the living substance and unite, making CO_2. The oxygen absorbed by the plant from the air unites with the living substance, or perhaps first with food substances, and from these the plant is replenished with carbon and oxygen. After the demonstration has been made, remove the glass plate which seals the thistle tube above, and pour in a small quantity of baryta water. The white precipitate formed affords another illustration that carbon dioxide is released.

227. Respiration is necessary for growth.—After performing experiment in paragraph 221, if the vessel has not been open too long so that oxygen has entered, we may use the vessel for another experiment, or set up a new one to be used in the course of 12 to 24 hours, after some oxygen has been consumed. Place some folded damp filter paper on the germinating peas in the jar. Upon this place one-half dozen peas which have just been germinated, and in which the roots are about 20–25 *mm* long. The vessel should be covered tightly again and set aside in a warm room. A second jar with water in the bottom instead of the germinating peas should be set up as a check. Damp folded filter paper should be supported above the water, and on this should be placed one-half dozen peas with roots of the same length as those in the jar containing carbon dioxide.

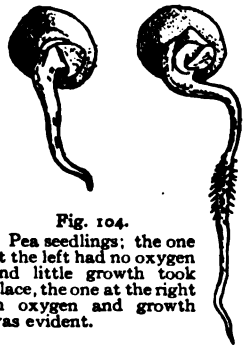

Fig. 104.

Pea seedlings; the one at the left had no oxygen and little growth took place, the one at the right in oxygen and growth was evident.

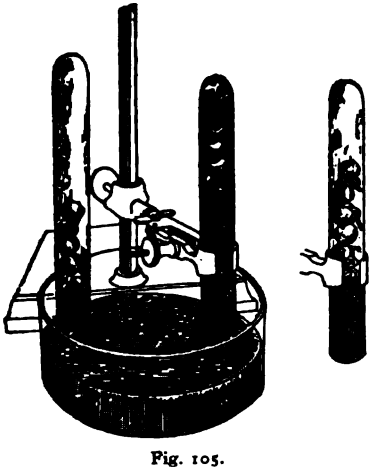

Fig. 105.

Experiment to show that growth takes place more rapidly in presence of oxygen than in absence of oxygen. The two tubes in the vessel represent the condition at the beginning of the experiment. At the close of the experiment the roots in the tube at the left were longer than those in the tube filled at the start with mercury. The tube outside of the vessel represents the condition of things where the peas grew in absence of oxygen; the carbon dioxide given off has displaced a portion of the mercury. This also shows *anaerobic* respiration.

228. In 24 hours examine and note how much growth has taken place. It will be seen that the roots have elongated but very little or none in the first jar, while in the second one we see that the roots have elongated considerably, if the experiment has been carried on carefully. Therefore in an atmosphere devoid of oxygen very little growth will take place, which shows that normal respiration with access of oxygen (aerobic respiration) is necessary for growth

229. Another way of performing the experiment.—If we wish we may use the following experiment instead of the simple one indicated above. Soak a handful of peas in water for 12–24 hours, and germinate so that twelve with the radicles 20–25 *mm* long may be selected. Fill a test tube with mercury and carefully invert it in a vessel of mercury so that there will

be no air in the upper end. Now nearly fill another tube and invert in the same way. In the latter there will be some air. Remove the outer coats from the peas so that no air will be introduced in the tube filled with the mercury, and insert them one at a time under the edge of the tube beneath the mercury, six in each tube, having first measured the length of the radicles. Place in a warm room. In 24 hours measure the roots. Those in the air will have grown considerably, while those in the other tube will have grown but little or none.

230. Anaerobic respiration.—The last experiment is also an excellent one to show *anaerobic* respiration. In the tube filled with mercury so that when inverted there will be no air, it will be seen after 24 hours that a gas has accumulated in the tube which has crowded out some of the mercury. With a wash bottle which has an exit tube properly curved, some water may be introduced in the tube. Then insert underneath a small stick of caustic potash. This will form a solution of potash, and the gas will be partly or completely absorbed. This shows that the gas was carbon dioxide. This evolution of carbon dioxide by living plants when there is no access of oxygen is anaerobic respiration (sometimes called intramolecular respiration). It occurs to a marked extent in the yeast plant.

231. Energy set free during respiration.—From what we have learned of the exchange of gases during respiration we infer that the plant loses carbon during this process. If the process of respiration is of any benefit to the plant, there must be some gain in some direction to compensate the plant for the loss of carbon which takes place.

It can be shown by an experiment that during respiration there is a slight elevation of the temperature in the plant tissues. The plant then gains some heat during respiration. Energy is also manifested by growth.

232. Respiration in a leafy plant.—We may take a potted plant which has a well-developed leaf surface and place it under a tightly fitting bell jar. Under the bell jar there also should be placed a small vessel containing baryta water. A similar apparatus should be set up, but with no plant, to serve as a check. The experiment must be set up in a room which is not frequented by persons, or the carbon dioxide in the room from respiration will vitiate the experiment. The bell jar containing the plant should be covered with a black cloth to prevent carbon assimilation. In the course of 10 or 12 hours, if everything has worked properly, the baryta water under the jar with the plant will show the film of barium carbonate, while the other one will show none. Respiration, therefore, takes place in a leafy plant as well as in germinating seeds

Fig. 106.

Test for liberation of carbon dioxide from leafy plant during respiration. Baryta water in smaller vessel. (Sachs.)

233. Respiration in fungi.—If several large actively growing mushrooms are accessible, place them in a tall glass jar as described for determining respiration in germinating peas. In the course of 12 hours test with the lighted taper and the baryta water. Respiration takes place in fungi as well as in green plants.

234. Respiration in plants in general.—Respiration is general in all plants, though not universal. There are some exceptions in the lower plants, notably in certain of the bacteria, which can only grow and thrive in the absence of oxygen.

235. Respiration a breaking-down process.—We have seen that in respiration the plant absorbs oxygen and gives off carbon dioxide. We should endeavor to note some of the effects of respiration on the plant. Let us take, say, two dozen dry peas, weigh them, soak for 12–24 hours in water, and, in the folds of a cloth kept moist by covering with wet paper or sphagnum, germinate them. When well germinated and before the green color appears dry well in the sun, or with artificial heat, being careful not to burn or scorch them. The aim should be to get them about as dry as the seed were before germination. Now weigh. The germinated seeds weigh less than the dry peas. There has then been a loss of plant substance during respiration.

236. Fermentation of yeast.—Take two fermentation tubes. Fill the closed tubular parts of each with a weak solution of grape sugar, or with potato decoction, leaving the open bulb nearly empty. Into the liquid of one of the tubes place a piece of compressed yeast as large as a pea. If the tubes are kept in a warm place for 24 hours bubbles of gas may be noticed rising in the one in which the yeast was placed, while in the second tube no such bubbles appear, especially if the filled tubes are first sterilized. The tubes may be kept until the first is entirely filled with the gas. Now dissolve in the liquid a small piece of caustic potash. Soon the gas will begin to be absorbed, and the liquid will rise until it again fills the tube. The gas was carbon dioxide, which was chiefly produced during the anaerobic respiration of the rapidly growing yeast cells. In bread making this gas is produced in considerable quantities, and rising through the dough fills it with numerous cavities containing gas, so that the bread "rises." When it is baked the heat causes the gas in the cavities to ex-

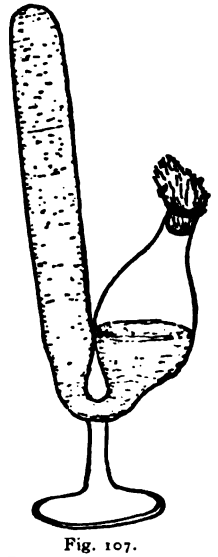

Fig. 107.
Fermentation tube with culture of yeast.

pand greatly. This causes the bread to "rise" more, and baked in this condition it is "light." There are two special processes accompanying the fermentation by yeast: 1st, the evolution of carbon dioxide as shown above; and, 2d, the formation of alcohol. The best illustration of this second process is the brewing of beer, where a form of the same organism which is employed in "bread rising" is used to "brew beer."

237. The yeast plant.—Before the caustic potash is placed in the tube some of the fermented liquid should be taken for study of the yeast plant, unless separate cultures are made for this purpose. Place a drop of the fermented liquid on a glass slip, place on this a cover-glass, and examine with the microscope. Note the minute oval cells with granular protoplasm. These are the yeast plant. Note in some a small "bud" at one side of the end. These buds increase in size and separate from the parent plant. The yeast plant is one celled, and multiplies by "budding" or "sprouting." It is a fungus, and some species of yeast like the present one do not form any mycelium. Under certain conditions, which are not very favorable for growth (example, when the yeast is grown in a weak nutrient substance on a thin layer of a plaster Paris slab), several spores are formed in many of the yeast cells. After a period of rest these spores will sprout and produce the yeast plant again. Because of this peculiar spore formation some place the yeast among the sac fungi. (See classification of the fungi.)

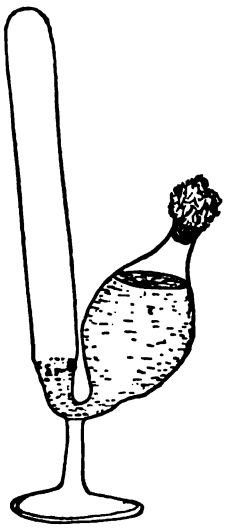

Fig. 108.
Fermentation tube filled with CO_2 from action of yeast in a sugar solution.

Fig. 108a.
Yeast. Saccharomyces cerivisiæ. *a*, small colony; *b*, single cell budding; *c*, single cell forming an ascus with four spores; *d*, spores free from the ascus. (After Rees.)

238. Organised ferments and unorganised ferments.—An organism like the yeast plant which produces a fermentation of a liquid with evolution of gas and alcohol is sometimes called a *ferment*, or *ferment organism*, or an *organized* ferment. On the other hand the diastatic ferments or enzymes like diastase, taka diastase, animal diastase (ptyalin in the saliva), cytase, etc., are *unorganized* ferments. In the case of these it is better to say *enzyme* and leave the word ferment for the ferment organisms.

239. Importance of green plants in maintaining purity of air.—By respiration, especially of animals, the air tends to become "foul" by the increase of CO_2. Green plants, i.e., plants with chlorophyll, purify the air during photosynthesis by absorbing CO_2 and giving off oxygen. Animals absorb in respiration large quantities of oxygen and exhale large quantities of CO_2. Plants absorb a comparatively small amount of oxygen in respiration and give off a comparatively small amount of CO_2. But they absorb during photosynthesis large quantities of CO_2 and give off large quantities of oxygen. In this way a balance is maintained between the two processes, so that the percentage of CO_2 in the air remains approximately the same, viz., about four-tenths of one per cent, while there are approximately 21 parts oxygen and 79 parts nitrogen

239a. Comparison of respiration and photosynthesis.

Starch formation or Photosynthesis.	Carbon dioxide is taken in by the plant and oxygen is liberated.
	Starch is formed as a result of the metabolism, or chemical change.
	The process takes place only in green plants, and in the green parts of plants, that is, in the presence of the chlorophyll. (Exception in purple bacterium.)
	The process only takes place under the influence of sunlight.
	It is a building-up process, because new plant substance is formed.
Respiration.	Oxygen is taken in by the plant and carbon dioxide is liberated.
	Carbon dioxide is formed as a result of the metabolism, or chemical change.
	The process takes place in all plants whether they possess chlorophyll or not (exceptions in anaerobic bacteria).
	The process takes place in the dark as well as in the sunlight.
	It is a breaking-down process, because disintegration of plant substance occurs.

CHAPTER XII.

GROWTH.

By growth is usually meant an increase in the bulk of the plant accompanied generally by an increase in plant substance. Among the lower plants growth is easily studied in some of the fungi.

240. Growth in mucor.—Some of the gonidia (often called spores) may be sown in nutrient gelatine or agar, or even in prune juice. If the culture has been placed in a warm room, in the course of 24 hours, or even less, the preparation will be ready for study.

241. Form of the gonidia.—It will be instructive if we first examine some of the gonidia which have not been sown in the culture medium. We should note their rounded or globose form, as well as their markings if they belong to one of the species with spiny walls. Particularly should we note the size, and if possible measure them with the micrometer, though this would not be absolutely necessary for a comparison, if the comparison can be made immediately. Now examine some of the gonidia which were sown in the nutrient medium. If they have not already germinated we note at once that they are much larger than those which have not been immersed in a moist medium.

242. The gonidia absorb water and increase in size before germinating.—From our study of the absorption of water or watery solutions of nutriment by living cells, we can easily understand the cause of this enlargement of the gonidium of the mucor when surrounded by the moist nutrient medium. The cell-sap in the spore takes up more water than it loses by diffu-

sion, thus drawing water forcibly through the protoplasmic membrane. Since it does not filter out readily, the increase in

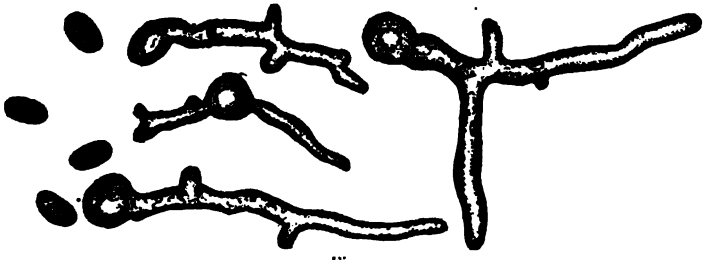

Fig. 109.

Spores of mucor, and different stages of germination.

quantity of the water in the cell produces a pressure from within which stretches the membrane, and the elastic cell wall yields. Thus the gonidium becomes larger.

243. How the gonidia germinate.—We should find at this time many of the gonidia extended on one side into a tube-like process the length of which varies according to time and temperature. The short process thus begun continues to elongate. This elongation of the plant is *growth*, or, more properly speaking, one of the phenomena of growth.

244. The germ tube branches and forms the mycelium.—In the course of a day or so branches from the tube will appear. This branched form of the threads of the fungus is, as we remember, the mycelium. We can still see the point where growth started from the gonidium. Perhaps by this time several tubes have grown from a single one. The threads of the mycelium near the gonidium, that is, the older portions of them, have increased in diameter as they have elongated, though this increase in diameter is by no means so great as the increase in length. After increasing to a certain extent in diameter, growth in this direction ceases, while apical growth is practically unlimited, being limited only by the supply of nutriment.

245. Growth in length takes place only at the end of the thread.—If there were any branches on the mycelium when the

culture was first examined, we can now see that they remain practically the same distance from the gonidium as when they were first formed. That is, the older portions of the mycelium do not elongate. Growth in length of the mycelium is confined to the ends of the threads.

246. Protoplasm increases by assimilation of nutrient substances.—As the plant increases in bulk we note that there is an increase in the protoplasm, for the protoplasm is very easily detected in these cultures of mucor. This increase in the quantity of the protoplasm has come about by the assimilation of the nutrient substance, which the plant has absorbed. The increase in the protoplasm, or the formation of additional plant substance, is another phenomenon of growth quite different from that of elongation, or increase in bulk.

247. Growth of roots.—For the study of the growth of roots we may take any one of many different plants. The seedlings of such plants as peas, beans, corn, squash, pumpkin, etc., serve excellently for this purpose.

248. Roots of the pumpkin.—The seeds, a handful or so, are soaked in water for about 12 hours, and then placed between layers of paper or between the folds of cloth, which must be kept quite moist but not very wet, and should be kept in a warm place. A shallow crockery plate, with the seeds lying on wet filter paper, and covered with additional filter paper, or with a bell jar, answers the purpose well.

The primary or first root (radicle) of the embryo pushes its way out between the seed coats at the small end. When the seeds are well germinated, select several which have the root 4–5*cm* long. With a crow-quill pen we may now mark the terminal portion of the root off into very short sections as in fig. 110. The first mark should be not more than 1*mm* from the tip, and the others not more than 1*mm* apart. Now place the seedlings down on damp filter paper, and cover with a bell jar so that they will remain moist, and if the season is cold place them in a warm room. At intervals of 8 or 10 hours, if convenient, observe them and note the farther growth of the root.

249. The region of elongation.—While the root has elongated, the region of elongation *is not at the tip of the root. It lies a little distance back from the tip*, beginning at about *2mm* from the tip and extending over an area represented by from 4–5 of the millimeter marks. The root shown in fig. 110 was marked at 10 A.M. on July 5. At 6 P.M. of the same day, 8

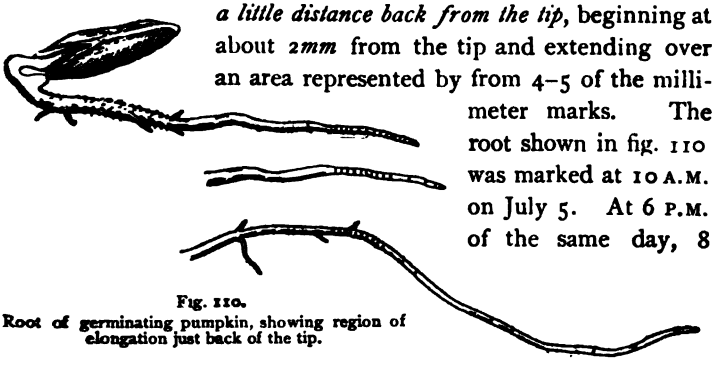

Fig. 110.
Root of germinating pumpkin, showing region of elongation just back of the tip.

hours later, growth had taken place as shown in the middle figure. At 9 A.M. on the following day, 15 hours later, the growth is represented in the lower one. Similar experiments upon a number of seedlings give the same result: the region of elongation in the growth of the root is situated a little distance back from the tip. Farther back very little or no elongation takes place, but growth in diameter continues for some time, as we should discover if we examined the roots of growing pumpkins, or other plants, at different periods.

250. Movement of region of greatest elongation.—In the region of elongation the areas marked off do not all elongate equally at the same time. The middle spaces elongate most rapidly and the spaces marked off by the 6, 7, and 8 *mm* marks elongate slowly, those farthest from the tip more slowly than the others, since elongation has nearly ceased here. The spaces marked off between the 2–4*mm* marks also elongate slowly, but soon begin to elongate more rapidly, since that region is becoming the region of greatest elongation. Thus the region of greatest elongation moves forward as the root grows, and remains approximately at the same distance behind the tip.

251. Formative region.—If we make a longitudinal section of the tip of a growing root of the pumpkin or other seedling, and examine it with the mi-

croscope, we see that there is a great difference in the character of the cells of the tip and those in the region of elongation of the root. First there is in the section a V-shaped cap of loose cells which are constantly being sloughed off. Just back of this tip the cells are quite regularly isodiametric, that is, of equal diameter in all directions. They are also very rich in protoplasm, and have thin walls. This is the region of the root where new cells are formed by division. It is the *formative region*. The cells on the outside of this area are the older, and pass over into the older parts of the root and root cap. If we examine successively the cells back from this *formative* region we find that they become more and more elongated in the direction of the axis of the root. The elongation of the cells in this older portion of the root explains then why it is that this region of the root elongates more rapidly than the tip.

252. Growth of the stem.—We may use a bean seedling growing in the soil. At the junction of the leaves with the stem there are enlargements. These are the *nodes*, and the spaces on the stem between successive nodes are the *internodes*. We should mark off several of these internodes, especially the younger ones, into sections about 5*mm* long. Now observe these at several times for two or three days, or more. The region of elongation is greater than in the case of the roots, and extends back farther from the end of the stem. In some young garden bean plants the region of elongation extended over an area of 40*mm* in one internode. See also Chapters 38, 39.

253. Force exerted by growth.—One of the marvelous things connected with the growth of plants is the force which is exerted by various members of the plant under certain conditions. Observations on seedlings as they are pushing their way through the soil to the air often show us that considerable force is required to lift the hard soil and turn it to one side. A very striking illustration may be had in the case of mushrooms which sometimes make their way through the hard and packed soil of walks or roads. That succulent and tender plants should be capable of lifting such comparatively heavy weights seems incredible until we have witnessed it. Very striking illustrations of the force of roots are seen in the case of trees which grow in rocky situations, where rocks of considerable weight are lifted, or small rifts in large rocks are widened by the lateral pressure exerted by the growth of a root, which entered when it was small and wedged its way in.

254. Zone of maximum growth.—Great variation exists in the rapidity of growth even when not influenced by outside conditions. In our study of the elongation of the root we found that the cells just back of the formative region

elongated slowly at first. The rapidity of the elongation of these cells increases until it reaches the maximum. Then the rapidity of elongation lessens as the cells come to lie farther from the tip. The period of maximum elongation here is the *zone of maximum growth* of these cells.

255. Just as the cells exhibit a zone of maximum growth, so the members of the plant exhibit a similar zone of maximum growth. In the case of leaves, when they are young the rapidity of growth is comparatively slow, then it increases, and finally diminishes in rapidity again. So it is with the stem. When the plant is young the growth is not so rapid; as it approaches middle age the rapidity of growth increases; then it declines in rapidity at the close of the season.

256. Energy of growth.—Closely related to the zone of maximum growth is what is termed the energy of growth. This is manifested in the comparative size of the members of a given plant. To take the sunflower for example, the lower and first leaves are comparatively small. As the plant grows larger the leaves are larger, and this increase in size of the leaves increases up to a maximum period, when the size decreases until we reach the small leaves at the top of the stem. The zone of maximum growth of the leaves corresponds with the maximum size of the leaves on the stem. The rapidity and energy of growth of the stem is also correlated with that of the leaves, and the zone of maximum growth is coincident with that of the leaves. It would be instructive to note it in the case of other plants and also in the case of fruits.

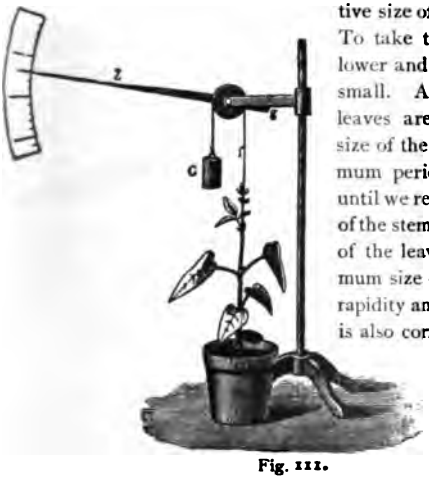

Fig. 111.
Lever auxanometer (Oels) for measuring elongation of the stem during growth.

257. Nutation.—During the growth of the stem all of the cells of a given section of the stem do not elongate simultaneously. For example the cells at a given moment on the south side are elongating more rapidly than the cells on the other side. This will cause the stem to bend slightly to the north. In a few moments later the cells on the west side are elongating more rapidly, and the stem is turned to the east; and so on, groups of cells in succession around the stem elongate more rapidly than the others. This causes the stem to describe a circle or ellipse about a central point. Since the region of greatest elongation of the cells of the stem is gradually moving toward the apex of the growing stem, this line of elongation of the cells which is

traveling around the stem does so in a spiral manner. In the same way, while the end of the stem is moving upward by the elongation of the cells, and at the same time is slowly moved around, the line which the end of the stem describes must be a spiral one. This movement of the stem, which is common to all stems, leaves, and roots, is *nutation.*

258. The importance of nutation to twining stems in their search for a place of support, as well as for the tendrils on leaves or stems, will be seen. In the case of the root it is of the utmost importance, as the root makes its way through the soil, since the particles of soil are more easily thrust aside. The same is also true in the case of many stems before they emerge from the soil.

CHAPTER XIII.

IRRITABILITY.

259. We should now examine the movements of plant parts in response to the influence of certain stimuli. By this time we have probably observed that the direction which the root and stem take upon germination of the seed is not due to the position in which the seed happens to lie. Under normal conditions we have seen that the root grows downward and the stem upward.

260. Influence of the earth on the direction of growth.— When the stem and root have been growing in these directions for a short time let us place the seedling in a horizontal position, so that the end of the root extends over an object of support in such a way that it will be free to go in any direction. It should be pinned to a cork and placed in a moist chamber. In the course of twelve to twenty-four hours the root which was formerly horizontal has turned the tip downward again. If we should mark off millimeter spaces beginning at the tip of the root, we should find that the motor zone, or region of curvature, lies in the same region as that of the elongation of the root.

Knight found that the stimulus which influences the root to turn downward is the force of gravity. The reaction of the root in response to this stimulus is geotropism, a turning influenced by the earth. This term is applied to the growth movements of plants influenced by the earth with regard to direction. While the motor zone lies back of the root tip, the latter receives the stimulus and is the perceptive zone. If the root tip is cut off, the root is no longer geotropic, and will not turn downward when placed in a horizontal position. Growth toward the earth

is *progeotropism*. The lateral growth of secondary roots is *diageotropism*.

The stem, on the other hand, which was placed in a horizontal position has become again erect. This turning of the stem in

Fig. 112.
Germinating pea placed in a horizontal position.

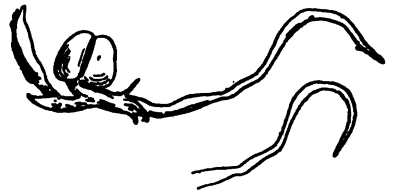

Fig. 113.
In 24 hours gravity has caused the root to turn downward.

Figs. 112, 113.—Progeotropism of the pea root.

the upward direction takes place in the dark as well as in the light, as we can see if we start the experiment at nightfall, or place the plant in the dark. This upward growth of the stem is also influenced by the earth, and therefore is a case of geotropism. The special designation in the case of upright stems is *negative geotropism*, or *apogeotropism*, or the stems are said to be *apogeotropic*.

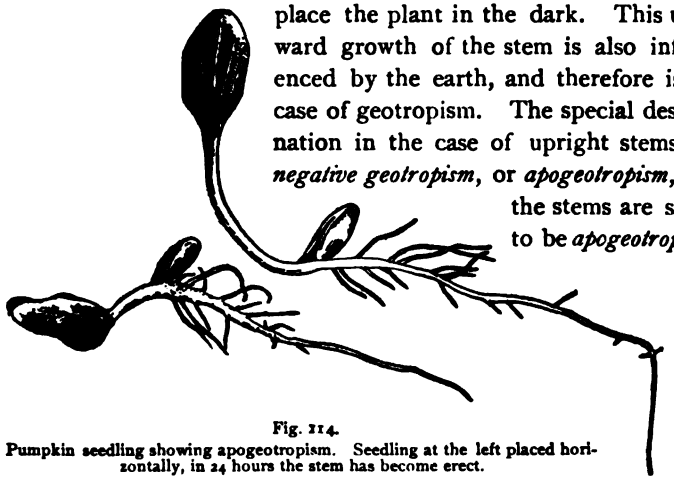

Fig. 114.
Pumpkin seedling showing apogeotropism. Seedling at the left placed horizontally, in 24 hours the stem has become erect.

If we place a rapidly growing potted plant in a horizontal position by laying the pot on its side, the ends of the shoots will soon turn upward again when placed in a horizontal position. Young bean plants growing in a pot began within two hours to turn the ends of the shoots upward.

Horizontal leaves and shoots can be shown to be subject to the same influence, and are therefore *diageotropic.*

261. Influence of light.—Not only is light a very important factor for plants during photosynthesis, it exerts great influence on plant growth and movement.

262. Growth in the absence of light.—Plants grown in the dark are subject to a number of changes. The stems are often longer, more slender and weaker since they contain a larger amount of water in proportion to building material which the plant obtains from carbohydrates manufactured in the light. On many plants the leaves are very small when grown in the dark.

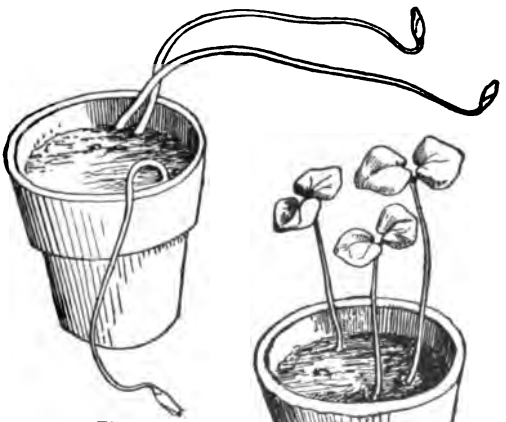

Fig. 115.
Radish seedlings grown in the dark, long, slender, not green.

Fig. 116.
Radish seedlings grown in the light, shorter, stouter, and green in color. Growth retarded by light.

263. Influence of light on direction of growth.—While we are growing seedlings, the pots or boxes of some of them should be placed so that the plants will have a one-sided illumination. This can be done by placing them near an open window, in a room with a one-sided illumination, or they may be placed in a box closed on all sides but one which is facing the window or light. In 12–24 hours, or even in a much shorter time in some cases, the stems of the seedlings will be directed toward the source of light. This influence exerted by the rays of light is *heliotropism*, a turning influenced by the sun or sunlight.

264. Diaheliotropism.—Horizontal leaves and shoots are *diaheliotropic* as well as *diageotropic.* The general direction

which leaves assume under this influence is that of placing them with the upper surface perpendicular to the rays of light which fall upon them. Leaves, then, exposed to the brightly lighted sky are, in general, horizontal. This position is taken in direct response to the stimulus of light. The leaves of plants with a one-sided illumination, as can be seen by trial, are turned with their upper surfaces toward the source of light, or perpendicular to the incidence of the light rays. In this way light overcomes for the time being the direction which growth gives to the leaves. The so-called "sleep" of plants is of course not sleep, though the leaves "nod," or hang downward, in many cases. There are many plants in which we can note this drooping of the leaves at nightfall, and in order to prove that it is not determined by the time of day we can resort to a well-known experiment to induce this condition during the day. The plant which has been used to illustrate this is the sunflower. Some of these plants, which

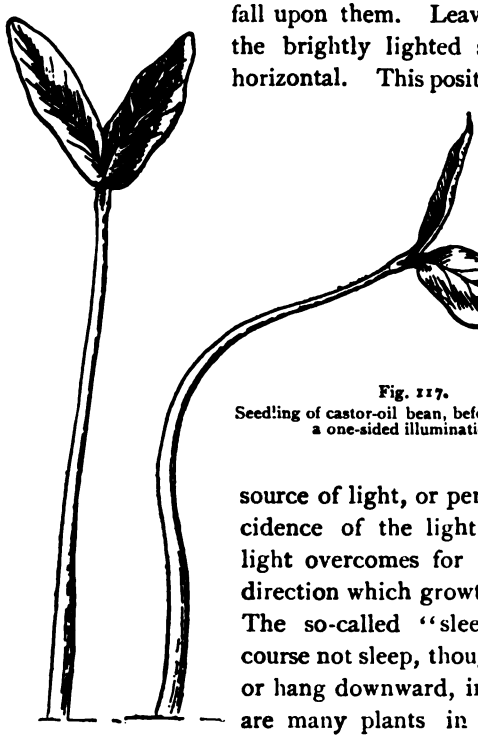

Fig. 117.
Seedling of castor-oil bean, before and after a one-sided illumination.

Fig. 118.
Dark chamber with opening at one side to show heliotropism. (After Schleichert.)

were grown in a box, when they were about 35*cm* high were covered for nearly two days, so that the light was excluded. At midday on the second day the box was removed, and the leaves on the covered plants are well represented by fig. 119, which was made from one of them. The leaves of the other plants in the box which were not covered were horizontal, as shown by fig. 120. Now on leaving these plants, which had exhibited

Fig. 120.
Sunflower plant removed from darkness, leaves extending under influence of light (diaheliotropism.)

induced "sleep" movements, exposed to the light they gradually assumed the horizontal position again.

Fig. 119.
Sunflower plant. Epinastic condition of leaves induced during the day in darkness.

265. Epinasty and hyponasty.—During the early stages of growth of many leaves, as in the sunflower plant, the direction of growth is different from what it is at a later period. The under surface of the young leaves grows more rapidly in a longitudinal direction than the upper side, so that the leaves are held upward close against the bud at the end of the stem. This is termed *hyponasty*, or the leaves are said to be *hyponastic*. Later the growth is more rapid on the upper side and the leaves turn downward or away from the bud. This is termed *epinasty*, or the leaves are said to be *epinastic*. This is shown by the night position of the leaves, or in the induced "sleep" of the sun-

flower plant in the experiment detailed above. The day position of the leaves on the other hand, which is more or less horizontal, is induced because of their irritability under the influence of light, the inherent downward or epinastic growth is overcome for the time. Then at nightfall or in darkness, the stimulus of light being removed, the leaves assume the position induced by the direction of growth.

266. In the case of the cotyledons of some plants it would seem that the growth was hyponastic even after they have opened. The day position of

Fig. 121.
Squash seedling. Position of cotyledons in light.

Fig. 122.
Squash seedling. Position of cotyledons in the dark.

the cotyledons of the pumpkin is more or less horizontal, as shown in fig. 121. At night, or if we darken the plant by covering with a tight box, the leaves assume the position shown in fig. 122.

While the horizontal position is the general one which is assumed by plants under the influence of light, their position is dependent to a certain extent on the intensity of the light as well as on the incidence of the light rays. Some plants are so strongly heliotropic that they change their positions all during the day.

267. Leaves with a fixed diurnal position.—Leaves of some plants when they are developed have a fixed diurnal position and are not subject to

variation. Such leaves tend to arrange themselves in a vertical or paraheliotropic position, in which the surfaces are not exposed to the incidence of light of the greatest intensity, but to the incidence of the rays of diffused light. Interesting cases of the fixed position of leaves are found in the so-called compass plants (like Silphium laciniatum, Lactuca scariola, etc.). In these the horizontal leaves arrange themselves with the surfaces vertical, and also pointing north and south, so that the surfaces face east and west.

268. Importance of these movements.—Not only are the leaves placed in a position favorable for the absorption of the rays of light which are concerned in making carbon available for food, but they derive other forms of energy from the light, as heat, which is absorbed during the day. Then with the nocturnal position, the leaves being drooped down toward the stem, or with the margin toward the sky, or with the cotyledons as in the pumpkin, castor-oil bean, etc., clasped upward together, the loss of heat by radiation is less than it would be if the upper surfaces of the leaves were exposed to the sky.

269. Influence of light on the structure of the leaf.—In our study of the structure of a leaf we found that in the ivy leaf the palisade cells were on the upper surface. This is the case with a great many leaves, and is the normal arrangement of "dorsiventral" leaves which are diaheliotropic. Leaves which are paraheliotropic tend to have palisade cells on both surfaces. The palisade layer of cells as we have seen is made up of cells lying very close together, and they thus prevent rapid evaporation. They also check to some extent the entrance of the rays of light, at least more so than the loose spongy parenchyma cells do. Leaves developed in the shade have looser palisade and parenchyma cells. In the case of some plants, if we turn over a very young leaf, so that the under side will be uppermost, this side will develop the palisade layer. This shows that light has a great influence on the structure of the leaf.

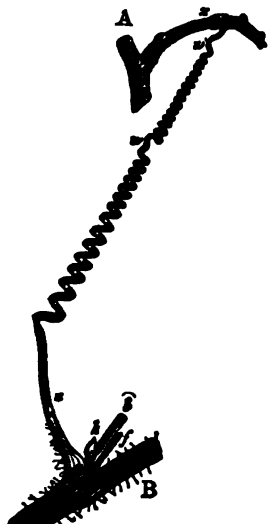

Fig. 123.
Coiling tendril of bryony.

270. Movement influenced by contact.—In the case of tendrils, twining leaves, or stems, the irritability to contact is shown in a movement of the tendril, etc., toward the object in touch. This causes the tendril or stem to coil around the object for support. The stimulus is also extended down the part of the tendril below the point of contact (see fig. 123), and that part coils

up like a wire coil spring, thus drawing the leaf or branch from which the tendril grows closer to the object of support. This coil between the object of support and the plant is also very important in easing up the plant when subject to violent gusts of wind which might tear the plant from its support were it not for the yielding and springing motion of this coil.

271. Sensitive plants.—These plants are remarkable for the rapid response to stimuli. Mimosa pudica is an excellent plant to study for this purpose.

272. Movement in response to stimuli.—If we pinch with the forceps one of the terminal leaflets, or tap it with a pencil, the two end leaflets fold above the "vein" of the pinna. This is immediately followed by the movement of the next pair, and so on as shown in fig. 125, until all the leaflets on this pinna are closed, then the stimulus travels down the other pinnæ in a similar manner, and soon the pinnæ approximate each other and the leaf then drops downward as shown in fig. 126. The normal position of the leaf is shown in fig. 124. If we jar the plant by striking it or by jarring the pot in which it is grown all the leaves quickly collapse into the position shown in fig. 126. If we examine the leaf now we see minute cushions at the base of each leaflet, at the junction of the pinnæ with the petiole, and a larger one at the junction of the petiole with the stem. We shall also note that the movement resides in these cushions.

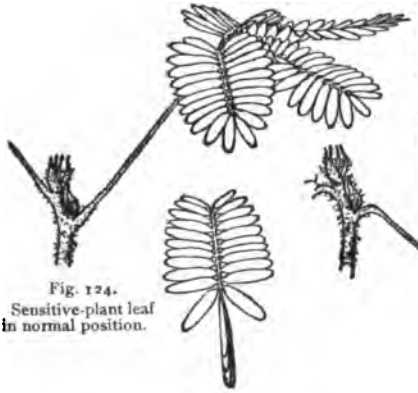

Fig. 124. Sensitive-plant leaf in normal position.

Fig. 125. Pinnæ folding up after stimulus.

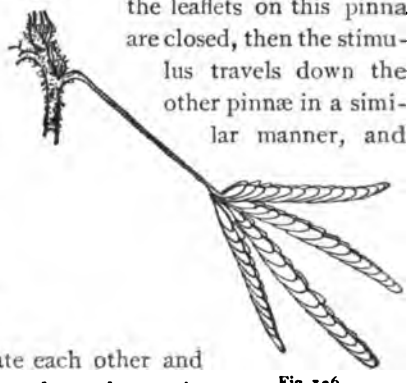

Fig. 126. Later all the pinnæ folded and leaf drooped.

273. Transmission of the stimulus.—The transmission of the stimulus in this mimosa from one part of the plant has been found to be along the cells of the bast.

274. Cause of the movement.—The movement is caused by a sudden loss of turgidity on the part of the cells in one portion of the pulvinus, as the cushion is called. In the case of the large pulvinus at the base of the petiole this loss of turgidity is in the cells of the lower surface. There is a sudden change in the condition of the protoplasm of the cells here so that they lose a large part of their water. This can be seen if with a sharp knife we cut off the petiole just above the pulvinus before movement takes place. A drop of liquid exudes from the cells of the lower side.

275. Paraheliotropism of the leaves of the sensitive plant.—If the mimosa plant is placed in very intense light the leaflets will turn their edges toward the incidence of the rays of light. This is also true of other plants in intense light, and is *paraheliotropism.* Transpiration is thus lessened, and chlorophyll is protected from too intense light.

We thus see that variations in the intensity of light have an important influence in modifying movements. Variations in temperature also exert a considerable influence, rapid elevation of temperature causing certain flowers to open, and falling temperature causing them to close.

Fig. 126.
Leaf of Venus fly-trap (Dionæa muscipula), showing winged petiole and toothed lobes.

Fig. 127.
Leaf of Drosera rotundifolia, some of the glandular hairs folding inward as a result of a stimulus.

276. Sensitiveness of insectivorous plants.—The Venus fly-trap (Dionæa muscipula) and the sundew (drosera) are interesting examples of sensitive plants, since the leaves close in response to the stimulus from insects.

277. Hydrotropism.—Roots are sensitive to moisture. They will turn toward moisture. This is of the greatest importance for the well-being of the plant, since the roots will seek those places in the soil where suitable moisture is present. On

the other hand, if the soil is too wet there is a tendency for the roots to grow away from the soil which is saturated with water. In such cases roots are often seen growing upon the surface of the soil so that they may obtain oxygen, which is important for the root in the processes of absorption and growth. Plants then may be injured by an excess of water as well as by a lack of water in the soil.

278 Temperature.—In the experiments on germination thus far made it has probably been noted that the temperature has much to do with the length of time taken for seeds to germinate. It also influences the rate of growth. The effect of different temperatures on the germination of seed can be very well noted by attempting to germinate some in rooms at various temperatures. It will be found, other conditions being equal, that in a moderately warm room, or even in one quite warm, 25–30 degrees centigrade, germination and growth goes on more rapidly than in a cool room, and here more rapidly than in one which is decidedly cold. In the case of most plants in temperate climates, growth may go on at a temperature but little above freezing, but few will thrive at this temperature.

279. If we place dry peas or beans in a temperature of about 70° C. for 15 minutes they will not be killed, but if they have been thoroughly soaked in water and then placed at this temperature they will be killed, or even at a somewhat lower temperature. The same seeds in the dry condition will withstand a temperature of 10° C. below, but if they are first soaked in water this low temperature will kill them.

280. In order to see the effect of freezing we may thoroughly freeze a section of a beet root, and after thawing it out place it in water. The water is colored by the cell-sap which escapes from the cells, just as we have seen it does as a result of a high temperature, while a section of an unfrozen beet placed in water will not color it if it was previously washed.

If the slice of the beet is placed at about — 6° C. in a shallow glass vessel, and covered, ice will be formed over the surface. If we examine it with the microscope ice crystals will be seen formed on the outside, and these will not be colored. The water for the formation of the crystals came from the cell-sap, but the concentrated solutions in the sap were not withdrawn by the freezing over the surface.

281. If too much water is not withdrawn from the cells of many plants in freezing, and they are thawed out slowly, the water which was withdrawn from the cells will be absorbed again and the plant will not be killed. But if the plant is thawed out quickly the water will not be absorbed, but will remain on the surface and evaporate. Some will also remain in the intercellular spaces, and the plant will die. Some plants, however, no matter how

slowly they are thawed out, are killed after freezing, as the leaves of the pumpkin, dahlia, or the tubers of the potato.

282. It has been found that as a general rule when plants, or plant parts, contain little moisture they will withstand quite high degrees of temperature, as well as quite low degrees, but when the parts are filled with sap or water they are much more easily killed. For this reason dry seeds and the winter buds of trees, and other plants, because they contain but little water, are better able to resist the cold of winters. But when growth begins in the spring, and the tissues of these same parts become turgid and filled with water, they are quite easily killed by frosts. It should be borne in mind, however, that there is great individual variation in plants in this respect, some being more susceptible to cold than others. There is also great variation in plants as to their resistance to the cold of winters, and of arctic climates, the plants of the latter regions being able to resist very low temperatures. We have examples also in the arctic plants, and those which grow in arctic climates on high mountains, of plants which are able to carry on all the life functions at temperatures but little above freezing.

For further discussion as to relation of plants to temperature, see Chapters 46, 48, 49, and 53.

PART II.

MORPHOLOGY AND LIFE HISTORY OF REPRESENTATIVE PLANTS.

CHAPTER XIV.

SPIROGYRA.

283. In our study of protoplasm and some of the processes of plant life we became acquainted with the general appearance of the plant spirogyra. It is now a familiar object to us. And in taking up the study of representative plants of the different groups, we shall find that in knowing some of these lower plants the difficulties of understanding methods of reproduction and relationship are not so great as they would be if we were entirely ignorant of any members of the lower groups.

284. Form of spirogyra.—We have found that the plant spirogyra consists of simple threads, with cylindrical cells attached end to end. We have also noted that each cell of the thread is exactly alike, with the exception of certain "holdfasts" on some of the species. If we should examine threads in different stages of growth we should find that each cell is capable of growth and division, just as it is capable of performing all the functions of nutrition and assimilation. The cells of spirogyra then multiply by division. Not simply the cells at the ends of the threads but any and all of the cells divide as they grow, and in this way the threads increase in length.

285. Multiplication of the threads.—In studying living material of this plant we have probably noted that the threads often become broken by two of the adjacent cells of a thread becoming separated. This may be and is accom-

plished in many cases without any injury to the cells. In this manner the threads or plants of spirogyra, if we choose to call a thread a plant, multiply, or increase. In this breaking of a thread the cell wall which separates any two cells splits. If we should examine several species of spirogyra we would probably find threads which present two types as regards the character of the walls at the ends of the cells. In fig. 128 we see that the ends are plain, that is, the cross walls are all straight. But in some other species the inner wall of the cells presents a peculiar appearance. This inner wall at the end of the cell is at first straight across. But it soon becomes folded back into the interior of its cell, just as the end of an empty glove finger may be pushed in. Then the infolded end is pushed partly out again, so that a peculiar figure is the result.

Fig. 128.
Thread of spirogyra, showing long cells, chlorophyll band, nucleus, strands of protoplasm, and the granular wall layer of protoplasm.

286. How some of the threads break.—In the separation of the cells of a thread this peculiarity is often of advantage to the plant. The cell-sap within the protoplasmic membrane absorbs water and the pressure pushes on the ends of the infolded cell walls. The inner wall being so much longer than the outer wall, a pull is exerted on the latter at the junction of the cells. Being weaker at this point the outer wall is ruptured. The turgidity of the two cells causes these infolded inner walls to push out suddenly as the outer wall is ruptured, and the thread is snapped apart as quickly as a pipe-stem may be broken.

287. Conjugation of spirogyra.—Under certain conditions, when vegetative growth and multiplication cease, a process of reproduction takes place which is of a kind termed sexual reproduction. If we select mats of spirogyra which have lost their deep green color, we are likely to find different stages of this sexual process, which in the case of spirogyra and related plants is called *conjugation*. A few threads of such a mat we should examine with the microscope. If the material is in the right condition we see in certain of the cells an oval or elliptical body. If we note carefully the cells in which these oval bodies are situated, there will be seen a tube at one side which con-

nects with an empty cell of a thread which lies near as shown in fig. 129. If we search through the material we may see other threads connected in this ladder fashion, in which the contents of the cells are in various stages of collapse from what we have seen in the growing cell. In some the protoplasm and chlorophyll band have moved but little from the wall; in others it forms a mass near the center of the cell, and again in others we will see that the contents of the cell of one of the threads has moved partly through the tube into the cell of the thread with which it is connected.

Fig. 129.
Zygospores of spirogyra.

289. This suggests to us that the oval bodies found in the cells of one thread of the ladder, while the cells of the other thread were empty, are formed by the union of the contents of the two cells. In fact that is what does take place. This kind of union of the contents of two similar or nearly similar cells is *conjugation*. The oval bodies which are the result of this conjugation are *zygotes*, or *zygospores*. When we are examining living material of spirogyra in this stage it is possible to watch this process of conjugation. Fig. 130 represents the different stages of conjugation of spirogyra.

290. How the threads conjugate, or join.—The cells of two threads lying parallel put out short processes. The tubes from two opposite cells meet and join. The walls separating the contents of the two tubes dissolve so that there is an open communication between the two cells. The content of each one of these cells which take part in the conjugation is a *gamete*. The one which passes through the tube to the receiving cell is the *supply-*

ing gamete, while that of the receiving cell is the *receiving gamete*.

291. How the protoplasm moves from one cell to another.—Before any movement of the protoplasm of the supplying cell takes place we can see

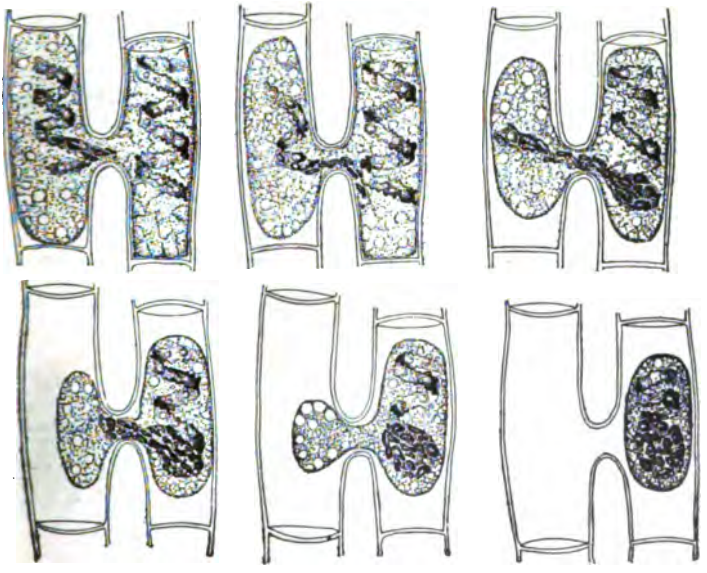

Fig. 130.

Conjugation in spirogyra; from left to right beginning in the upper row is shown the gradual passage of the protoplasm from the supplying gamete to the receiving gamete.

that there is great activity in its protoplasm. Rounded vacuoles appear which increase in size, are filled with a watery fluid, and swell up like a vesicle, and then suddenly contract and disappear. As the vacuole disappears it causes a sudden movement or contraction of the protoplasm around it to take its place. Simultaneously with the disappearance of the vacuole the membrane of the protoplasm is separated from a part of the wall. This is probably brought about by a sudden loss of some of the water in the cell-sap. These activities go on, and the protoplasmic membrane continues to slip away from the wall. Every now and then there is a movement by which the protoplasm is moved a short distance. It is moved toward the tube and finally a portion of it with one end of the chlorophyll band begins to move into the tube. About this time the vacuoles can be seen in an active condition in the receptive cell. At short intervals movement con-

tinues until the content of the supplying cell has passed over into that of the receptive cell. The protoplasm of this one is now slipping away from the cell wall, until finally the two masses round up into the one zygospore.

292. The zygospore.—This zygospore now acquires a thick wall which eventually becomes brown in color. The chlorophyll color fades out, and a large part of the protoplasm passes into an oily substance which makes it more resistant to conditions which would be fatal to the vegetative threads. The zygospores are capable therefore of enduring extremes of cold and dryness which would destroy the threads. They pass through a "resting" period, in which the water in the pond may be frozen, or dried, and with the oncoming of favorable conditions for growth in the spring or in the autumn they germinate and produce the green thread again.

293. Life cycle.—The growth of the spirogyra thread, the conjugation of the gametes and formation of the zygospore, and the growth of the thread from the zygospore again, makes what is called a complete *life cycle.*

294. Fertilization.—While conjugation results in the fusion of the two masses of protoplasm, fertilization is accomplished when the nuclei of the two cells come together in the zygospore and fuse into a single nucleus. The

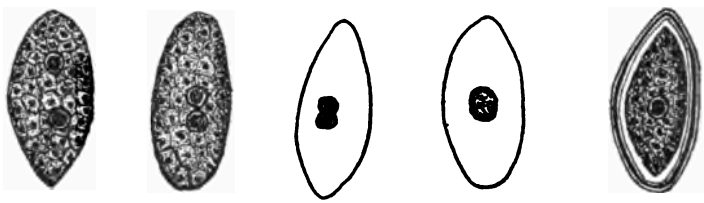

Fig. 131.

Fertilization in spirogyra; shows different stages of fusion of the two nuclei, with mature zygospore at right. (After Overton.)

different stages in the fusion of the two nuclei of a recently formed zygospore are shown in figure 131.

In the conjugation of the two cells, the chlorophyll band of the supplying cell is said to degenerate, so that in the new plant the number of chlorophyll bands in a cell is not increased by the union of the two cells.

295. Simplicity of the process.—In spirogyra any cell of the thread may form a gamete (excepting the holdfasts of some species). Since all of the cells of a thread are practically alike, there is no structural difference between a vegetative cell and a cell about to conjugate. The difference is a physiological one. All the cells are capable of conjugation if the physiological conditions are present. All the cells therefore are potential gametes. (Strictly speaking the wall of the cell is the *gametangium*, while the content forms the gamete.)

While there is sometimes a slight difference in size between the conjugat-

ing cells, and the supplying cell may be the smaller, this is not general. We say, therefore, that there is no differentiation among the gametes, so that usually before the protoplasm begins to move one cannot say which is to be the supplying and which the receiving gamete.

296. Position of the plant spirogyra.—From our study then we see that there is practically no differentiation among the vegetative cells, except where holdfasts grow out from some of the cells for support. They are all alike in form, in capacity for growth, division, or multiplication of the threads. Each cell is practically an independent plant. There is no differentiation between vegetative cell and conjugating cell. All the cells are potential gametes. Finally there is no structural differentiation between the gametes. This indicates then a simple condition of things, a low grade of organization.

297. The alga spirogyra is one of the representatives of the lower algæ belonging to the group called *Conjugatæ*. Zygnema with star-shaped chloroplasts, mougeotia with straight or sometimes twisted chlorophyll bands, belong to the same group. In the latter genus only a portion of the protoplasm of each cell unites to form the zygospore, which is located in the tube between the cells.

Fig. 132.
Closterium.

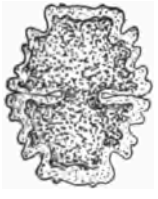

Fig. 133.
Micrasterias.

Fig. 134.
Xanthidium.

Fig. 135.
Staurastrum.

Fig. 136.
Euastrum.

Fig. 137.
Cosmarium.

298. The desmids also belong to the same group. The desmids usually live as separate cells. Many of them are beautiful in form. They grow entangled among other algæ, or on the surface of aquatic plants, or on wet soil. Several genera are illustrated in figures 132–137.

CHAPTER XV.

VAUCHERIA.

299. The plant vaucheria we remember from our study in an earlier chapter. It usually occurs in dense mats floating on the water or lying on damp soil. The texture and feeling of these mats remind one of "felt," and the species are sometimes called the "green felts." The branched threads are continuous, that is there are no cross walls in the vegetative threads. This plant multiplies itself in several ways which would be too tedious to detail here. But when fresh bright green mats can be obtained they should be placed in a large vessel of water and set in a cool place. Only a small amount of the alga should be placed in a vessel, since decay will set in more rapidly with a large quantity. For several days one should look for small green bodies which may be floating at the side of the vessel next the lighted window.

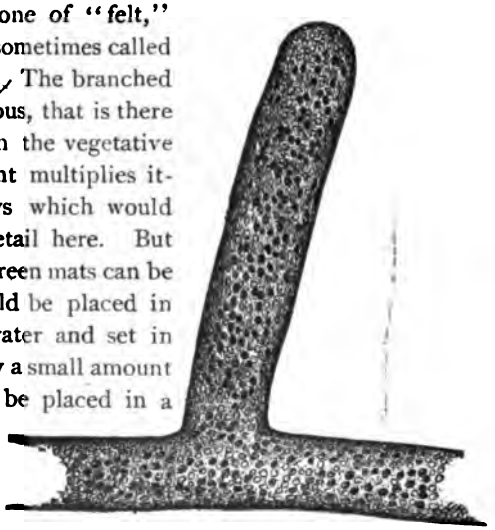

Fig. 138.
Portion of branched thread of vaucheria

300. Zoogonidia of vaucheria.—If these minute floating green bodies are found, a small drop of water containing them should be mounted for exami-

nation. If they are rounded, with slender hair-like appendages over the surface, which vibrate and cause motion, they very likely are one of the kinds of reproductive bodies of vaucheria. The hair-like appendages are *cilia*, and they occur in pairs, several of them distributed over the surface. These rounded bodies are *gonidia*, and because they are motile they are called *zoogonidia*.

By examining some of the threads in the vessel where they occurred we may have perhaps an opportunity to see how they are produced. Short branches are formed on the threads, and the contents are separated from those of the main thread by a septum. The protoplasm and other contents of this branch separate from the wall, round up into a mass, and escape through an opening which is formed in the end. Here they swim around in the water for a time, then come to rest, and germinate by growing out into a tube which forms another vaucheria plant. It will be observed that this kind of reproduction is not the result of the union of two different parts of the plant. It thus differs from that which is termed sexual reproduction. A small part of the plant simply becomes separated from it as a special body, and then grows into a new plant, a sort of multiplication. This kind of reproduction has been termed *asexual reproduction.*

301. Sexual reproduction in vaucheria.—The organs which are concerned in sexual reproduction in vaucheria are very readily obtained for study if one collects the material at the right season. They are found quite readily during the spring and autumn, and may be preserved in formalin for study at any season, if the material cannot be collected fresh at the time it is desired for study. Fine material for study often occurs on the soil of pots in greenhouses during the winter. While the zoogonidia are more apt to be found in material which is quite green and freshly growing, the sexual organs are usually more abundant when the threads appear somewhat yellowish, or yellow green.

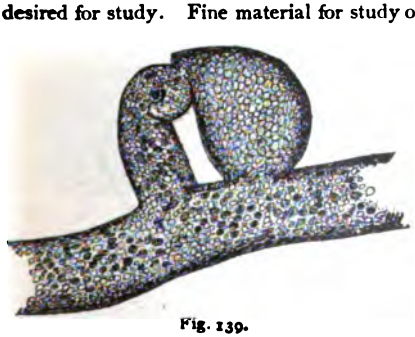

Fig. 139.

Young antheridium and oogonium of Vaucheria sessilis, before separation from contents of thread by a septum.

302. Vaucheria sessilis; the sessile vaucheria.—In this plant the sexual organs are sessile, that is they are not borne on a stalk as in some other species. The sexual organs usually occur several in a group. Fig. 139 represents a portion of a fruiting plant.

303. Sexual organs of vaucheria. Antheridium.—The antheridia are short, slender, curved branches from a main thread. A septum is formed which separates an end portion from the stalk. This end cell is the *antheridium*. Frequently it is collapsed or empty as shown in fig. 140. The protoplasm in

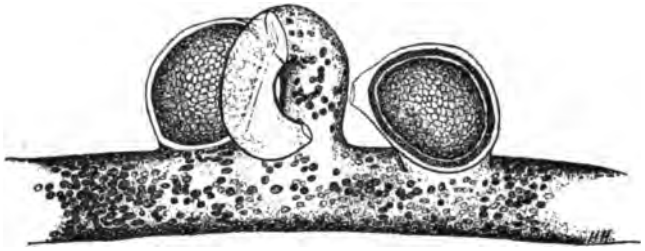

Fig. 140.
Vaucheria sessilis, one antheridium between two oogonia.

the antheridium forms numerous small oval bodies each with two slender lashes, the cilia. When these are formed the antheridium opens at the end and they escape. It is after the escape of these spermatozoids that the antheridium is collapsed. Each spermatozoid is a male gamete.

304. Oogonium.—The oogonia are short branches also, but they become large and somewhat oval. The septum which separates the protoplasm from that of the main thread is as we see near the junction of the branch with the main thread. The oogonium, as shown in the figure, is usually turned somewhat to one side. When mature the pointed end opens and a bit of the protoplasm escapes. The remaining protoplasm forms the large rounded egg cell which fills the wall of the oogonium. In some of the oogonia which we examine this egg is surrounded by a thick brown wall, with starchy and oily contents. This is the

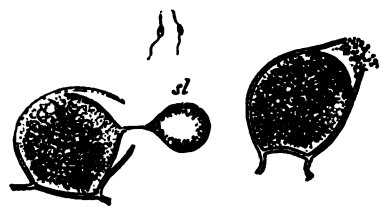

Fig. 141.
Vaucheria sessilis; oogonium opening and emitting a bit of protoplasm; spermatozoids; spermatozoids entering oogonium. (After Pringsheim and Goebel.)

fertilized egg (sometimes called here the oospore). It is freed from the oogonium by the disintegration of the latter, sinks into

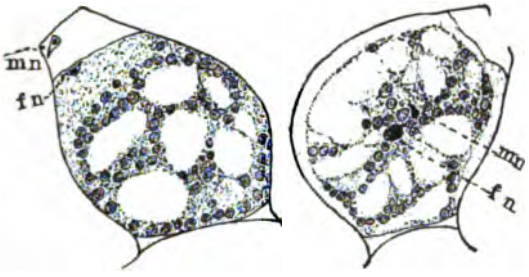

Fig. 142.

Fertilization in vaucheria. *mn*, male nucleus; *fn*, female nucleus. Male nucleus entering the egg and approaching the female nucleus. (After Oltmanns.)

the mud, and remains here until the following autumn or spring, when it grows directly into a new plant.

305. Fertilization.—Fertilization is accomplished by the spermatozoids swimming in at the open end of the oogonium,

Fig. 143.

Fertilization of vaucheria. *fn*, female nucleus; *mn*, male nucleus. The different figures show various stages in the fusion of the nuclei.

when one of them makes its way down into the egg and fuses with the nucleus of the egg.

306. The twin vaucheria (V. geminata).—Another species of vaucheria is the twin vaucheria. This is also a common one, and may be used for study instead of the sessile vaucheria if the latter cannot be obtained. The sexual organs are borne at the end of a club-shaped branch. There are usually two oogonia, and one antheridium between them which terminates the branch. In a closely related species, instead of the two oogonia there is a whorl of them with the antheridium in the center.

307. Vaucheria compared with spirogyra.—In vaucheria we have a plant which is very interesting to compare with spirogyra in several respects

Growth takes place, not in all parts of the thread, but is localized at the ends of the thread and its branches. This represents a distinct advance on such a plant as spirogyra. Again, only specialized parts of the plant in vaucheria form the sexual organs. These are short branches. Farther there is a great difference in the size of the two organs, and especially in the size of the gametes, the supplying gametes (spermatozoids) being very minute, while the receptive gamete is large and contains all the nutriment for the fertilized egg. In spirogyra, on the other hand, there is usually no difference in size of the gametes, as we have seen, and each contributes equally in the matter of nutriment for the fertilized egg. Vaucheria, therefore, represents a distinct advance, not only in the vegetative condition of the plant, but in the specialization of the sexual organs. Vaucheria, with other related algæ, belongs to a group known as the *Siphoneæ*, so called because the plants are tube-like or *siphon*-like.

308. Botrydium granulatum. — An example of one of the simpler members of the Siphoneæ is Botrydium granulatum. It is found sometimes in abundance on wet ground which is colored green or red by its presence, according to the stage of development. The plant body is long pear-shaped, the smaller end attached to the ground by slender branched rhizoids (Fig. 143). The protoplasm contains many nuclei and lines the inside of the wall. When multiplication takes place large numbers of small zoospores with one cilium each are formed in the protoplasm, and escape at free end. Reproduction takes place by two-ciliated gametes, which fuse in pairs to form zygospores. In dry seasons the protoplasm in the pear-shaped plant passes down into the rhizoids and forms small rounded *planospores*.

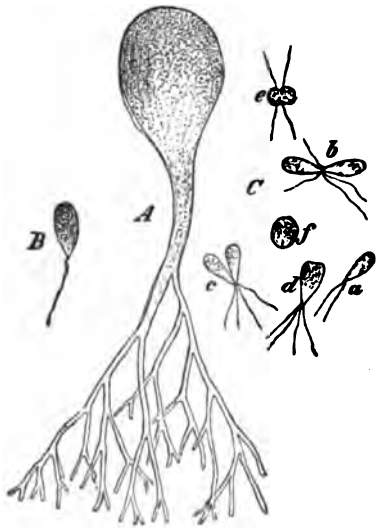

Fig. 143*a*.

Botrydium granulatum. *A*, the whole plant; *B*, swarm spore; *C*, planogametes; *a*, a single gamete; *b–e*, two gametes in process of fusion; *f*, zygote.

All the stages of development are too complicated to describe here.

CHAPTER XVI.

ŒDOGONIUM.

309. Œdogonium is also an alga. The plant is sometimes associated with spirogyra, and occurs in similar situations. Our attention was called to it in the study of chlorophyll bodies. These we recollect are, in this plant, small oval disks, and thus differ from those in spirogyra.

310. Form of œdogonium.—Like spirogyra, œdogonium forms simple threads which are made up of cylindrical cells placed end to end. But the plant is very different from any member of the group to which spirogyra belongs. In the first place each cell is not the equivalent of an individual plant as in spirogyra. Growth is localized or confined to certain cells of the thread which divide at one end in such a way as to leave a peculiar overlapping of the cell walls in the form of a series of shallow caps or vessels (fig. 144), and this is one of the characteristics of this genus. Other differences we find in the manner of reproduction.

311. Fruiting stage of œdogonium.—Material in the fruiting stage is quite easily obtainable, and may be preserved for study in formalin if there is any doubt about obtaining it at the time we need it for study. This condition of the plant is easily detected because of the swollen condition of some of the cells, or by the presence of brown bodies with a thick wall in some of the cells.

312. Sexual organs of œdogonium. Oogonium and egg.—The enlarged cell is the oogonium, the wall of the cell being the wall of the oogonium. (See fig. 145.) The protoplasm inside, before

fertilization, is the egg cell. In those cases where the brown body with a thick wall is present fertilization has taken place, and this body is the *fertilized egg*, or *oospore*. It contains large quantities of an oily substance, and, like

Fig. 144.

Portion of thread of œdogonium, showing chlorophyll grains, and peculiar cap cell walls.

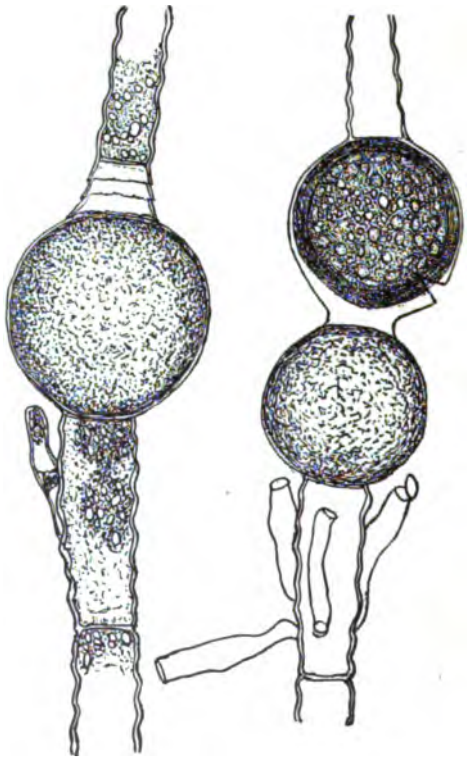

Fig. 145.

Œdogonium undulatum, with oogonia and dwarf males; the upper oogonium at the right has a mature oospore.

the fertilized egg of spirogyra and vaucheria, is able to withstand greater changes in temperature than the vegetative stage, and can endure drying and freezing for some time without injury.

In the oogonium wall there can frequently be seen a rift near the middle of one side, or near the upper end. This is the

opening through which the spermatozoid entered to fecundate the egg.

313. Dwarf male plants.—In some species there will also be seen peculiar club-shaped dwarf plants attached to the side of the oogonium, or near it, and in many cases the end of this dwarf plant has an open lid on the end.

314. Antheridium.—The end cell of the dwarf male in such species is the *antheridium*. In other species the spermatozoids are developed in different cells (antheridia) of the same thread which bears the oogonium, or on a different thread.

315. Zoospore stage of œdogonium.—The egg after a period of rest starts into active life again. In doing so it does not develop the thread-like plant directly as in the case of vaucheria and spirogyra. It first divides into four zoospores which are exactly like the zoogonidia in form. (See fig. 152.) These germinate and develop the thread form again. This is a quite remarkable peculiarity of œdogonium when compared with either vaucheria or spirogyra. It is the introduction of an intermediate stage between the fertilized egg and that form of the plant which bears the sexual organs, and should be kept well in mind.

316. Asexual reproduction.—Material for the study of this stage of œdogonium is not readily obtainable just when we wish it for study. But fresh plants brought in and placed in a quantity of fresh water may yield suitable material, and it should be examined at intervals for several days. This kind of reproduction takes place by the formation of *zoogonidia*. The entire contents of a cell round off into an oval body, the wall of the cell breaks, and the zoogonidium escapes. It has a clear space at the small end, and around this clear space is a row or crown of cilia as shown in fig. 146. By the vibration of these cilia the zoogonidium swims around for a time, then settles down on some object of support, and several slender holdfasts grow out in the form of short rhizoids which attach the young plant.

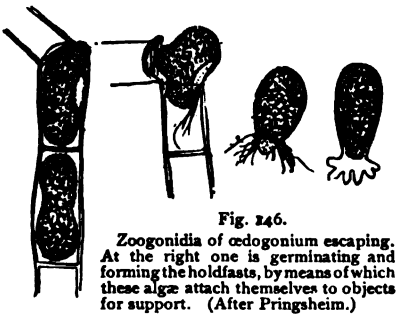

Fig. 146.
Zoogonidia of œdogonium escaping. At the right one is germinating and forming the holdfasts, by means of which these algæ attach themselves to objects for support. (After Pringsheim.)

317. Sexual reproduction. Antheridia.—The antheridia are short cells which are formed by one of the ordinary cells dividing into a number of disk-shaped ones as shown in fig. 147. The protoplasm in each antheridium

forms two spermatozoids (sometimes only one) which are of the same form as the zoogonidia but smaller, and yellowish instead of green. In some species a motile body intermediate in size and color between the spermatozoids and zoogonidia is first formed, which after swimming around comes to rest on the oogonium, or near it, and develops what is called a "dwarf male plant" from which the real spermatozoid is produced.

Fig. 147.
Portion of thread of œdogonium showing antheridia

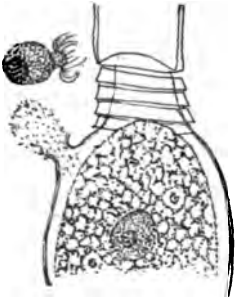

Fig. 148.
Portion of thread of œdogonium showing upper half of egg open, and a spermatozoid ready to enter. (After Klebahn).

318. Oogonia. — The oogonia are formed directly from one of the vegetative cells. In most species this cell first enlarges in diameter, so that it is easily detected. The protoplasm inside is the egg cell. The oogonium wall opens, a bit of the protoplasm is emitted, and the spermatozoid then enters and fertilizes it (fig. 148). Now a hard brown wall is formed around it, and, just as in spirogyra

Fig. 149.
Male nucleus just entering egg at left side.

Fig. 150.
Male nucleus fusing with female nucleus.

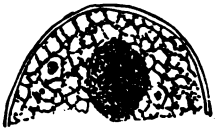

Fig. 151.
The two nuclei fused, and fertilization complete.

Figs. 149–151.— Fertilization in œdogonium. (After Klebahn).

and vaucheria, it passes through a resting period. At the time of germination it does not produce the thread-like plant again directly, but first forms four zoospores exactly like the zoogonidia (fig. 152). These zoospores then germinate and form the plant.

319. Œdogonium compared with spirogyra.—Now if we compare œdogonium with spirogyra, as we did in the case of vaucheria, we find here also that there is an advance upon the simple condition which exists in spirogyra. Growth and division of the thread is limited to certain portions. The sexual organs are differentiated. They usually differ in form and size from the vegetative cells, though the oogonium is simply a changed vegetative

cell. The sexual organs are differentiated among themselves, the antheridium is small, and the oogonium large. The gametes are also differentiated in size, and the male gamete is motile, and carries in its body the nucleus which fuses with the nucleus of the egg cell.

But a more striking advance is the fact that the fertilized egg does not

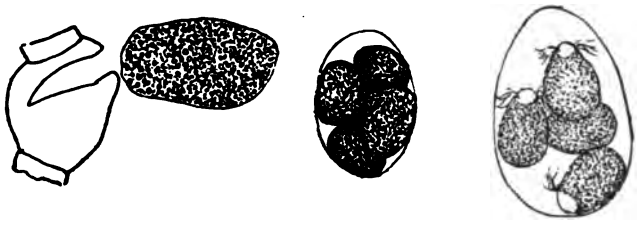

Fig. 152.

Fertilized egg of œdogonium after a period of rest escaping from the wall of the oogonium, and dividing into the four zoospores. (After Juranyi.)

produce the vegetative thread of œdogonium directly, but first forms four zoospores, each of which is then capable of developing into the thread. On the other hand we found that in spirogyra the zygospore develops directly into the thread form of the plant.

Fig. 153.

Tuft of chætophora, natural size.

320. Position of œdogonium.—Œdogonium is one of the true thread-like algæ, green in color, and the threads are divided into distinct cells. It, along with many relatives, was once placed in the old genus conferva. These are all now placed in the group *Confervoideæ*, that is, the *conferva-like algæ*.

Fig. 154.

Portion of chætophora showing branching.

321. Relatives of œdogonium.—Many other genera are related to œdogonium. Some consist of simple threads, and others of branched threads. An example of the branched forms is found in chætophora, represented in figures 153, 154. This plant grows in quiet pools or in slow-running water. It is attached to sticks, rocks, or to larger aquatic plants. Many threads spring from the same point of attachment and radiate in all directions. This, together with the branching of the threads, makes a small, compact, greenish, rounded mass, which is

held firmly together by a gelatinous substance. The masses in this species are about the size of a small pea, or smaller. Growth takes place in chætophora at the ends of the threads and branches. That is, growth is apical. This, together with the branched threads and the tendency to form cell masses, is a great advance of the vegetative condition of the plant upon that which we find in the simple threads of œdogonium.

CHAPTER XVII.

COLEOCHÆTE.

322. Among the green algæ coleochæte is one of the most interesting. Several species are known in this country. One of these at least should be examined if it is possible to obtain it. It occurs in the water of fresh lakes and ponds, attached to aquatic plants.

323. The shield-shaped coleochæte.—This plant (C. scutata)

Fig. 155.
Stem of aquatic plant showing coleochæte, natural size.

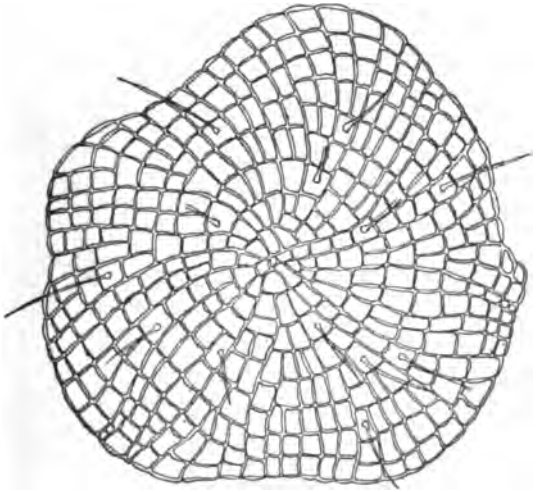

Fig. 156.
Thallus of Coleochæte scutata.

is in the form of a flattened, circular, green plate, as shown in fig. 156. It is attached near the center on one side to rushes

and other plants, and has been found quite abundantly for several years in the waters of Cayuga Lake at its southern extremity. As will be seen it consists of a single layer of green cells which radiate from the center in branched rows to the outside, the cells lying so close together as to form a continuous plate. The plant started its growth from a single cell at the central point, and grew at the margin in all directions. Sometimes they are quite irregular in outline, when they lie quite closely side by side and interfere with one another by pressure. If the surface is examined carefully there will be found long hairs, the base of which is enclosed in a narrow sheath. It is from this character that the genus takes its name of coleochæte (sheathed hair).

324. Fruiting stage of coleochæte.—It is possible at some seasons of the year to find rounded masses of cells situated near the margin of this green disk. These have developed from a fertilized egg which remained attached to the plant, and probably by this time the parent plant has lost its color.

325. Zoospore stage.—This mass of tissue does not develop directly into the circular green disk, but each of the cells forms a zoospore. Here then, as in œdogonium, we have another stage of the plant interpolated between the fertilized egg and that stage of the plant which bears the gametes. But in coleochæte we have a distinct advance in this stage upon what is present in œdogonium, for in coleochæte the fertilized egg develops first into a several-celled mass of tissue before the zoospores are formed, while in œdogonium only four zoospores are formed directly from the egg.

Fig. 157.

Portion of thallus of Coleochæte scutata, showing empty cells from which zoogonidia have escaped, one from each cell; zoogonidia at the left. (After Pringsheim.)

Fig 158.

Portion of thallus of Coleochæte scutata, showing four antheridia formed from one thallus cell; a single spermatozoid at the right. (After Pringsheim.)

326. Asexual reproduction.—In asexual reproduction any of the green cells on the plant may form zoogonida. The contents of a cell round off and

form a single zoogonidium which has two cilia at the smaller end of the oval body, fig. 157. After swimming around for a time they come to rest, germinate, and produce another plant.

327. Sexual reproduction.—Oogonium.—The oogonium is formed by the enlargement of a cell at the end of one of the threads, and then the end of the

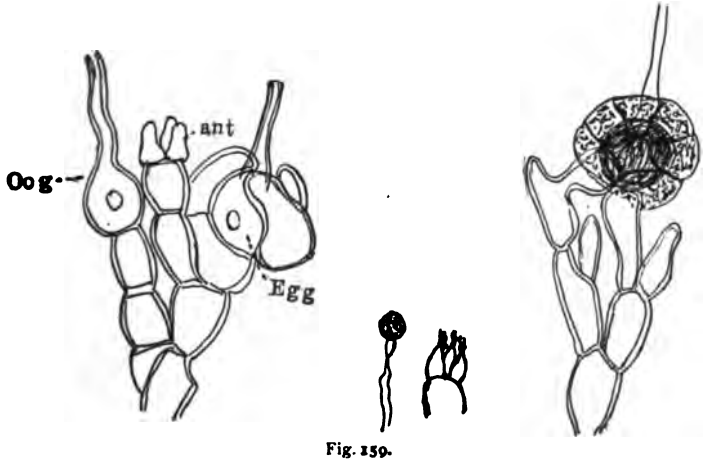

Fig. 159.

Coleochæte soluta; at left branch bearing oogonium (*oog*); antheridia (*ant*); egg in oogonium and surrounded by enveloping threads; at center three antheridia open, and one spermatozoid; at right sporocarp, mature egg inside sporocarp wall.

cell elongates into a slender tube which opens at the end to form a channel through which the spermatozoid may pass down to the egg. The egg is formed of the contents of the cell (fig. 159). Several oogonia are formed on one plant, and in such a plant as C. scutata they are formed in a ring near the margin of the disk.

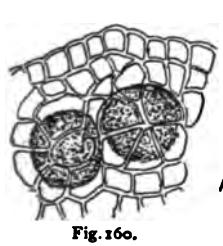

Fig. 160.

Two sporocarps still surrounded by thallus. Thallus finally decays and sets sporocarp free.

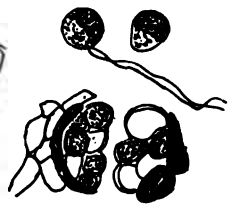

Fig. 161.

Sporocarp ruptured by growth of egg to form cell mass. Cells of this sporophyte forming zoospores.

Figs. 160, 161. C. scutata.

328. Antheridia.—In C. scutata certain of the cells of the plant divide into four smaller cells, and each one of these becomes an antheridium. In C. soluta the antheridia grow out from the end of terminal cells in the form of short flasks, sometimes four in number or less (fig. 159). A single spermatozoid is formed from the contents. It is oval and possesses two long cilia. After swim-

ming around it passes down the tube of the oogonium and fertilizes the egg.

329. Sporocarp.—After the egg is fertilized the cells of the threads near the egg grow up around it and form a firm covering one cell in thickness. This envelope becomes brown and hard, and serves to protect the egg. This is the "fruit" of the coleochæte, and is sometimes called a sporocarp (spore fruit). The development of the cell mass and the zoospores from the egg has been described above.

Some of the species of coleochæte consist of branched threads, while others form circular cushions several layers in thickness. These forms together with the form of our plant C. scutata make an interesting series of transitional forms from filamentous structures to an expanded plant body formed of a mass of cells.

330. COMPARATIVE TABLE FOR SPIROGYRA, VAUCHERIA, ŒDOGONIUM, COLEOCHÆTE.

	GAMETOPHYTE. (Bears the sexual organs and gonidia.)						SPORO-PHYTE. Bears spores	How Veg. Phase of Gametophyte is Developed.
	Vegetative Phase	Growth.	Multiplication.	Sexual Reproduction.				
				Sexual Organs.		Gametes.	Fruit.	
Spirogyra.	Simple threads of cylindrical cells.	All cells divide and grow.	By breaking up of threads.	Undifferentiated. Any cell of thread. Conjugate by tube.		Undifferentiated. Entire contents of conjugating cell.	Zygospore Rests.	Develops veg. phase directly.
Vaucheria.	Branched threads, continuous.	Limited to ends of threads and branches.	By multiciliate zoogonidia, and other cells, from terminal portions.	Differentiated. Antheridia slender cells on special branches.	Oogonium, large rounded cell, on special branch, opens and emits bit of protoplasm.	Differentiated. Small two-ciliated spermatozoids. Large egg cell.	Egg (or oospore). Rests.	Develops veg. phase directly.
Œdogonium.	Simple threads of cylindrical cells.	Limited to certain portions of thread.	By oval zoogonidia, with crown of cilia. Any cell may form a single zoogonidium.	Differentiated. Antheridia disk-shaped, several from one vegetative cell. Sometimes on dwarf males.	Oogonium, changed vegetative cell, opens and emits bit of protoplasm.	Differentiated. Oval spermatozoids with crown of cilia. Two from each antheridium. Large egg cell.	Egg (or oospore). Rests.	Divides into four cells; each forms zoospore which develops veg. phase again.
Coleochæte.	Branched threads, or compact circular plates.	Terminal or marginal.	By zoogonidia with two cilia. Any cell may form a single zoogonidium.	Differentiated. Antheridia, four or several from single veg. cell.	Oogonium, enlarged veg. cell, with long tube through opening of which spermatozoid enters. After fertilization wall of enveloping threads surrounds oogonium.	Differentiated. Oval, biciliate spermatozoid, one from each antheridium. Large egg cell.	Egg (surrounded by wall from gametophyte). Rests. Divides and grows to form a mass of cells.	Each forms a zoospore. Zoospore develops veg. phase again.

CHAPTER XVIII.

CLASSIFICATION AND ADDITIONAL STUDIES OF THE ALGÆ.

In order to show the general relationship of the algæ studied, the principal classes are here enumerated as well as some of the families. In some of the groups not represented by the examples studied above, a few species are described which may serve as the basis of additional studies if desired. The principal classes * of algæ are as follows:

Class Chlorophyceæ.

331. These are the green algæ, so called because the chlorophyll green is usually not masked by other pigments, though in some forms it is. There are three subclasses.

332. Subclass PROTOCOCCOIDEÆ.—In the Protococcoideæ are found the simplest green plants. Many of them consist of single cells which live an independent life. Others form "colonies," loose aggregations of individuals not yet having attained the permanency of even a simple plant body, for the cells often separate readily and are able to form new colonies. The colonies are often held together by a gelatinous membrane, or matrix. Some are motile, while others are non-motile. A few of the families are here enumerated.

333. Family Volvocaceæ.—These are all motile, during the vegetative stage. The individuals are single or form more or less globose colonies.

334. The "red snow" plant (Sphærella nivalis).—This is often found in arctic and alpine regions forming a red covering over more or less large areas of snow or ice. For this reason it is called the "red snow plant."

335. Sphærella lacustris, a closely related species, is very widely distributed in temperate regions along streams or on the borders of lakes and

* In Engler & Prantl's Pflanzenfamilien, Wille uses the term class for these principal subdivisions of the algæ. Systematists are not yet agreed upon a uniform use of the terms.

ponds. Here in dry weather it is often found closely adhering to the dry rock surface, and giving it a reddish color as if the rock were painted. This is especially the case in the shallow basins formed over the uneven surface of the rock near the water's edge. These places during heavy rains or in high water are provided with sufficient water to fill the basins. During such times the red snow plant grows and multiplies, loses its red color and

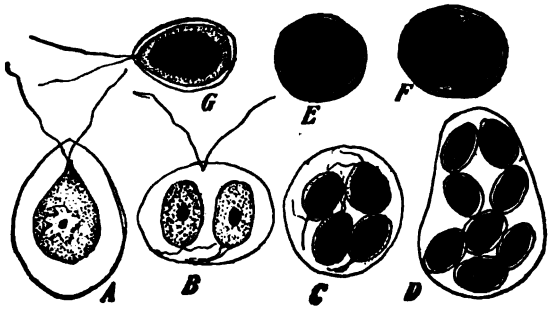

Fig. 161.

Sphærella lacustris (Girod.) Wittrock. *A*, mature free-swimming individual with central red spot. *B*, division of mother individual to form two. *C*, division of a red one to form four. *D*, division into eight. *E*, a typical resting cell, red. *F*, same beginning to divide. *G*, one of four daughter zoospores after swimming around for a time losing its red color and becoming green. (After Hazen.)

becomes green, and, being motile, is free swimming. It is a single-celled plant, oval in form, surrounded by a gelatinous sheath and with two cilia or flagella at the smaller end, by the vibration of which it moves (fig. 162). The single cell multiplies by dividing into two cells. When the water dries out of the basin, the motile plant comes to rest, and many of the cells assume the red color. To obtain the plant for study, scrape some of the red covering from these rock basins and place it in fresh spring water, and in a day or so the swarmers are likely to be found. Under certain conditions small microzoids are formed.

336. Chlamydomonas is a very interesting genus of motile one-celled green algæ, because the species are closely related to the Flagellates among the lower animals. The plant is oval, with a single chloroplast and surrounded by a gelatinous envelope through which the two cilia or flagella extend. One-celled organisms of this kind are sometimes called *monads*, i.e., a one-celled being. This one has a gelatinous cloak and is, therefore, a *cloaked monad* (*Chlamydomonas*). The species often are found as a very thin green film on fresh water. C. pulvisculus is shown in fig. 163. When it multiplies the single cell divides into two, as shown in *B*. Sometimes a non-motile palmella stage is formed, as shown in *C* and *D*. Reproduction

takes place by gametes which are of unequal size, the smaller one representing the sperm and the larger one the egg as in *E* and *F*. These con-

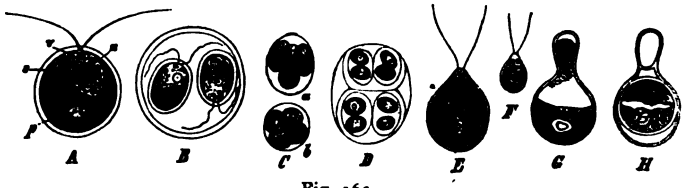

Fig. 163.

Chlamydomonas pulvisculus (Müll.) Ehrb. *A*, an old motile individual; *n*, nucleus; *p*, pyrenoid; *s*, red eye spot; *v*, contractile vacuole; *B*, motile individual has drawn in its cilia and divided into two; *C*, mother plant has drawn in its cilia and divided into four non-motile cells; *D*, pamella stage; *E*, female gamete—egg; *F*, male gamete—sperm; *G*, early stage of conjugation; *H*, zygospore with conjugating tube and empty male cell attached. (After Wille.)

jugate as in *G* and *II*, the protoplasm of the smaller one passing over into the larger one, and a zygospore is thus formed.

337. Of those which form colonies, Pandorina morum is widely distributed and not rare. It consists of a sphere formed of sixteen individuals enclosed in a thin gelatinous membrane. Each cell possesses two cilia (or flagella), which extend from the broader end out through the enveloping membrane. By the movement of these flagella the colony goes rolling around in the water. When the plant multiplies each individual cell divides into sixteen small cells, which then grow and form new colonies. Reproduction takes place when the individual cells of the young colonies separate, and usually a small individual unites with a larger one and a zygospore is formed (see fig. 164). Eudorina elegans is somewhat similar, but when the gametes are formed certain mother cells divide into sixteen small motile males or sperms, and certain other mother cells divide into sixteen large motile females or eggs. These separate from the colonies, and the sperms pair with the eggs and fuse to form zygospores. This plant as well as Chlamydomonas pulvisculus foreshadows the early differentiation of sex in plants.

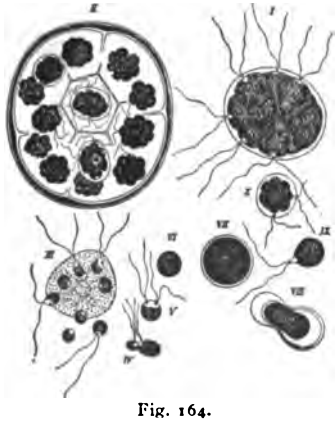

Fig. 164.

Pandorina morum (Müll.) Bory. I, motile colony; II, colony divided into 16 daughter colonies; III, sexual colony, gametes escaping; IV, V, conjugating gametes; VI, VII, young and old zygospore; VIII, zygospore forming a large swarm spore, which is free in IX; X, same large swarm spore divided to form young colony. (After Pringsheim.)

338. Family Tetrasporaceæ.—This family is well represented by Tetraspora lubrica forming slimy green net-like sheets attached to objects in slow-running water. It is really a single-celled plant. The rounded cells divide by cross walls into four cells, and these again, and so on, large numbers being held in loose sheets by the slime in which they are imbedded.

339. Family Pleurococcaceæ.—The members of this family are all non-motile in the vegetative stage. They consist of single individuals, or of colonies. Pleurococcus vulgaris (Protococcus vulgaris) is a single-celled alga, usually obtained with little difficulty. It is often found on the shaded, and cool, or moist side of trees, rocks, walls, etc., in damp places. This plant is not motile. It multiplies by fission (fig. 165) into two, then four, etc. These cells remain united for a time, then separate. Sometimes the cells are found growing out into filaments, and it is thought by some that P. vulgaris may be only a simple stage of a higher alga. Eremosphæra viridis is another single-celled alga found in fresh water among filamentous forms. The cells are large and globose.

Fig. 165. Pleurococcus (protococcus) vulgaris.

340. Family Hydrodictyaceæ.—These plants form colonies of cells. Hydrodictyon reticulatum, the water net, is made up of large numbers of cylindrical cells so joined at their ends as to form a large open mesh or net. Pediastrum forms circular flat colonies, as shown in fig. 166. Both of these

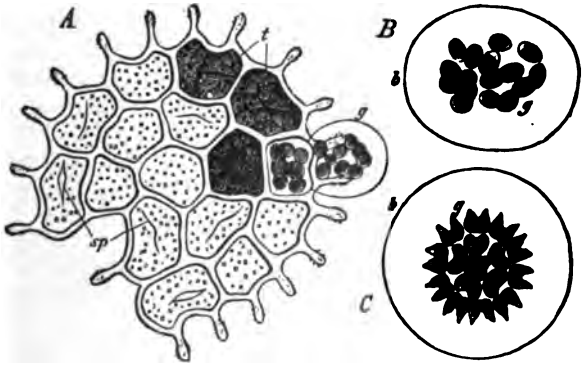

Fig. 166.

Pediastrum boryanum. *A*, mature colony, most of the young colonies have escaped from their mother cells; at *g*, a young colony is escaping; *sp*, empty mother cells; *B*, young colony; *C*, same colony with spores arranged in order. (After Braun.)

plants are rather common in fresh-water pools, the latter one intermingled with filamentous algæ, while the former forms large sheets or nets. Multiplication in Hydrodictyon takes place by the protoplasm in one of the cells

dividing into thousands of minute cells, which gradually arrange themselves in the form of a net, escape together from the mother cell, and grow into a large net. In Pediastrum multiplication takes place in a similar way, but the protoplasm in each cell usually divides into sixteen small cells, and escaping together from the mother cell arrange themselves and grow to full size (fig. 166).

341. The Conjugatæ include several families of green algæ, which probably should be included among the Chlorophyceæ. They have probably had their origin from some of the more simple members of the Protococcoideæ. They are represented by Spirogyra, Zygnema, and the desmids, studied in Chapter 14.

342. Subclass CONFERVOIDEÆ.—These are mostly filamentous algæ, the filaments being composed of cells firmly united, and, with the exception of the simplest forms, there is a definite growing point. A few of the families are as follows:

343. Family Ulvaceæ.—These contain the sea wracks, or sea lettuce, like Ulva, forming expanded green, ribbon-like growths in the sea.

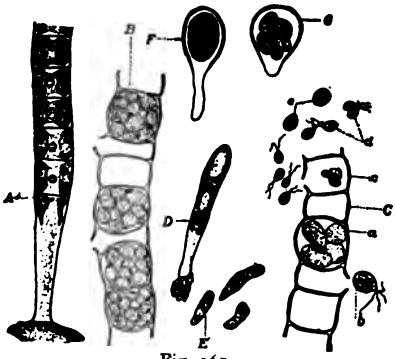

Fig. 167.

Ulothrix zonata. *A*, base of thread. *B*, cells with zoospores, *C*, one cell with zoospores escaping another cell with small biciliate gametes escaping and some fusing to form zygospores. *E*, zoospores germinating and forming threads *F*, *G*, zygospore growing and forming zoospores. (After Caldwell and Dodel-Port.)

344. Family Ulotrichaceæ, represented by Ulothrix zonata, not uncommon in slow-running water or in ponds of fresh water attached to rocks or wood. It consists of simple threads of short cells. Multiplication takes place by zoospores. Reproduction takes place by motile sexual cells (gametes) which fuse to form a zygospore (fig. 167).

345. Family Chætophoraceæ, represented by Chætophora (in Chapter 15) and Draparnaudia in fresh water.

346. Family Œdogoniaceæ, represented by Œdogonium (Chapter 16).

347. Family Coleochætaceæ, represented by Coleochæte (Chapter 17).

348. Subclass SIPHONEÆ.—There are several families.

349. Family Botrydiaceæ.—This is represented by Botrydium granulatum (Chapter 15, p. 146).

350. Family Vaucheriaceæ, represented by Vaucheria (Chapter 15), with quite a large number of species, is widely distributed.

Class Schizophyceæ (= Cyanophyceæ).

351. The Blue-Green Algæ, or **Cyanophyceæ** form slimy looking thin mats on damp wood or the ground, or floating mats or scum on the water. The color is usually bluish green, but in some species it is purple, red or brown. All have chlorophyll, but it is not in distinct chloroplasts and is more or less completely guised by the presence of other pigments. Two orders and eight families are recognized. The following include some of our common forms:

352. ORDER COCCOGONALES (COCCOGONEÆ).—Single-celled plants, occurring singly or in colonies, in some forms forming short threads. One of the two families is mentioned.

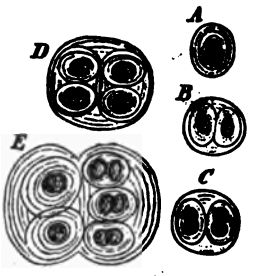

Fig. 168.
Gloeocapsa.

353. Family Chroococcaceæ. — The plants multiply only through cell division. Chroococcus, forms rounded, blue-green cells enclosed in a thick gelatinous coat, in fresh water and in damp places; certain species form "lichengonidia" in some genera of lichens. Gloeocapsa is similar to Chroococcus, but the colonies are surrounded by an additional common gelatinous envelope (fig. 168); on damp rocks, etc.

354. ORDER HORMOGONALES (HORMOGONEÆ).—Plants filamentous, simple celled or with false or true branching, usually several celled (Spirulina is single celled). Multiplication takes place through *hormogones*, short sections of the threads becoming free; also through resting cells. Two of the six families are mentioned.

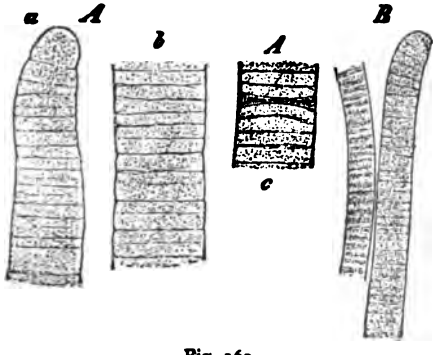

Fig. 169.

A, Oscillatoria princeps, *a* terminal cell; *b*, *c*, portions from the middle of a filament. In *c*, a dead cell is shown between the living cells; *B*, Oscillatoria froelichii, *b*, with granules along the partition walls.

355. Family Oscillatoriaceæ.—This family is represented by the genus Oscillatoria, and by several other genera common and widely distributed. Oscillatoria contains many species. They are found on the damp ground or wood, or floating in mats in the water. They often form on

the soil at the bottom of the pool, and as gas becomes entangled in the mat of threads, it is lifted from the bottom and floated to the surface of the water. The plant is thread-like, and divided up into many short cells. The threads often show an oscillating movement, whence the name *Oscillatoria*.

356. Family Nostocaceæ.—This family is represented by Nostoc, which forms rounded, slimy, blue-green masses on wet rocks. The individual plants in the slimy ball resemble strings of beads, each cell being rounded, and several of these arranged in chains as shown in fig. 170. Here and there are often found larger cells (heterocysts) in the chain. Nostoc punctiforme lives in the intercellular spaces of the roots of cycads (often found in greenhouses), and in the stems of Gunnera. N. sphæricum lives in the spaces between the cells in many species of liverworts (in the genera Anthoceros, Blasia, Pellia, Aneura, Riccia, etc.), and in the perforated cells of Sphagnum acutifolium. Anabæna is another common and widely distributed genus. The species occur in fresh or salt water, singly or in slimy masses. Anabæna azollæ lives endophytically in the leaves of the water fern, Azolla.

Fig. 170.

Nostoc linckii. *A*, filament with two heterocysts (*h*), and a large number of spores (*sp*); *B*, isolated spore beginning to germinate; *C*, young filament developed from spore. (After Bornet.)

Class Schizomycetes.

357. Bacteriales.—The bacteria are sometimes classified with the Cyanophyceæ, under the name Schizophyta, and represent the subdivision Schizomycetes, or fission fungi, because many of them multiply by a division of the cells just as the blue-green algæ do. For example, Bacillus forms rods which increase in length and divide into two rods, or it may grow into a long thread of many short rods. Micrococcus consists of single rounded cells. Streptococcus forms chains of rounded cells, Sarcina forms irregular cubes of rounded cells, while others like Spirillum are spiral in form. Bacillus subtilis may be obtained by making an infusion from hay and

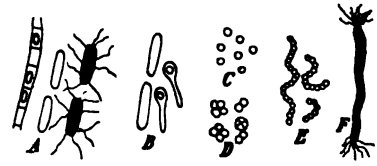

Fig. 171.

Bacteria. *A*, Bacillus subtilis. Spores in threads, unstained rods, and stained rods showing cilia; *B*, Bacillus tetani, the tetanus or lockjaw bacillus, found in garden soil and on old rusty nails. Spores in club-shaped ends. *C*, Micrococcus; *D*, Sarcina; *E*, Streptococcus; *F*, Spirillum. (After Migula.)

allowing it to stand for several days. Bacillus tetani occurs in the soil, on old rusty nails, etc. It is called the tetanus bacillus because it causes a permanent spasm of certain muscles, as in "lockjaw." This bacillus grows and produces this result on the muscles when it occurs in deep and closed wounds such as are caused by stepping on an old nail or other object which pierces the flesh deeply. In such a deep wound oxygen is deficient, and in this condition the bacillus is virulent. Opening the wounds to admit oxygen and washing them out with a solution of bichloride of mercury prevents the tetanus. Many bacteria are of great importance in bringing about the decay of dead animal and plant matter, returning it to a condition for plant food. (See also nitrate and nitrite bacteria, Chapter IX.) While most bacteria are harmless there are many which cause very serious diseases of man and animals, as typhoid fever, diphtheria, tuberculosis, etc., while some others produce disease in plants. Others aid in certain fermentations or liquids and are employed for making certain kinds of wines or other beverages. Some work in symbiosis with yeasts, as in the kephir yeast, used in fermenting certain crude beverages by natives of some countries.

357*a*. **Myxobacteriales (Myxobacteriaceæ Thaxter *).**—These plants consist of colonies of bacteria-like organisms, motile rods, which multiply by cross-division and secrete a gelatinous substance or matrix which surrounds the colonies. They form plasmodium-like masses which superficially resemble the slime moulds. In the fruiting stage some species become elevated from the substratum into cylindrical, clavate, or branched forms, which bear cysts of various shapes containing the rods in a resting stage, or the rods are converted into spore-like masses. Ex., Chondromyces crocatus on decaying plant parts, Myxobacter aureus on wet wood and bark, Myxococcus rubescens on dung, decaying lichens, paper, etc.

Class Flagellata.

358. **The flagellates** are organisms of very low organization resembling animals as much as they do plants. They are single celled and possess two cilia or flagella, by the vibration of which they move. Some are without a cell wall, while others have a well-defined membrane, but it rarely consists of cellulose. Some have chromatophores and are able to manufacture carbohydrates like ordinary green plants. These are green in Euglena, and brown in Hydrurus. Some possess a mouth-like opening and are able to injest solid particles of food (more like animals), while others have no such opening and absorb food substances dissolved in water (more like plants). The Euglena viridis is not uncommon in stagnant water, often forming a greenish film on the water.

* See Bot. Gaz., 17, 389, 1892.

Class Peridineæ.

358*a*. These are peculiar one-celled organisms provided with two flagella and show some relationship to the Flagellates. They usually are provided with a cellulose membrane, which in some forms consists of curiously sculptured plates. In the higher forms this cellulose membrane consists of two valves fitting together in such a way as to resemble some of the diatoms. Like the Flagellates, some have green chromatophores, which in some are obscured by a yellow or brown pigment (resembling the diatoms), while still others have no chlorophyll. The Peridineæ are abundant in the sea, while some are found in fresh water.

Class Diatomaphyceæ (Bacillariales, Diatomaceæ).

358*b*. The diatoms are minute and peculiar organisms believed to be algæ. They live in fresh, brackish, and salt water. They are often found covering the surface of rocks, sticks, or the soil in thin sheets. They occur singly and free, or several individuals may be joined into long threads, or other species may be attached to objects by slender gelatinous stalks. Each

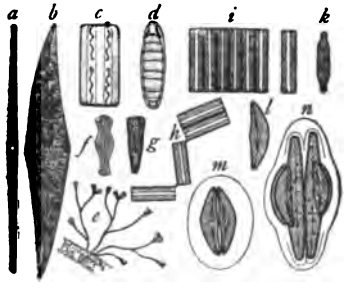

Fig. 171*a*.

A group of Diatoms: *c* and *d*, top and side views of the same form; *e*, colony of stalked forms attached to an alga; *f* and *g*, top and side views of the form shown at *e*; *h*, a colony; *i*, a colony, the top and side view shown at *k* and *n*, forming auxospores. (After Kerner.)

protoplast is enclosed in a silicified skeleton in the form of a box with two halves, often shaped like an old-fashioned pill box, one-half fitting over the other like the lid of a box. It is evident that in this condition the plant cannot increase much in size.

They multiply by fission. This takes place longitudinally. i.e., in the direction of the two halves or *valves* of the box. Each new plant then has a valve only on one side. A new valve is now formed over the naked half, and fits inside the old valve. At each division the individuals thus become smaller and smaller until they reach a certain point, when the valves are cast off and the cell forms an *auxospore*, i.e., it grows alone, or after conjugation with another, to the full size again, and eventually provides itself

with new valves. The valves are often marked with numerous and fine lines, often making beautiful figures, and some are used for test objects for microscopes.

The free forms are capable of movement. The movement takes place in the longitudinal direction of the valves. They glide for some time in one direction, and then stop and move back again. It is not a difficult thing to mount them in fresh water and observe this movement.

The diatoms have small chlorophyll plates, but the green color is disguised by a brownish pigment called diatomin. The relationships of the diatoms are uncertain, but some, because of the color, think they are related to the Phæophyceæ.

Class Phæophyceæ.

359. The brown algæ. (Phæophyceæ).—The members of this class possess chlorophyll, but it is obscured by a brown pigment. The plants are accessible at the seashore, and for inland laboratories may be preserved in formalin (2½ per cent). (See also Chapter LVI.)

360. Ectocarpus.—The genus Ectocarpus represents well some of the simpler forms of the brown algæ (fig. 172). They are slender, filamentous branched algæ growing in tufts, either epiphytic on other marine algæ (often on Fucaceæ), or on stones. The slender threads are only divided crosswise, and thus consist of long series of short cells. The sporangia are usually plurilocular (sometimes uni-

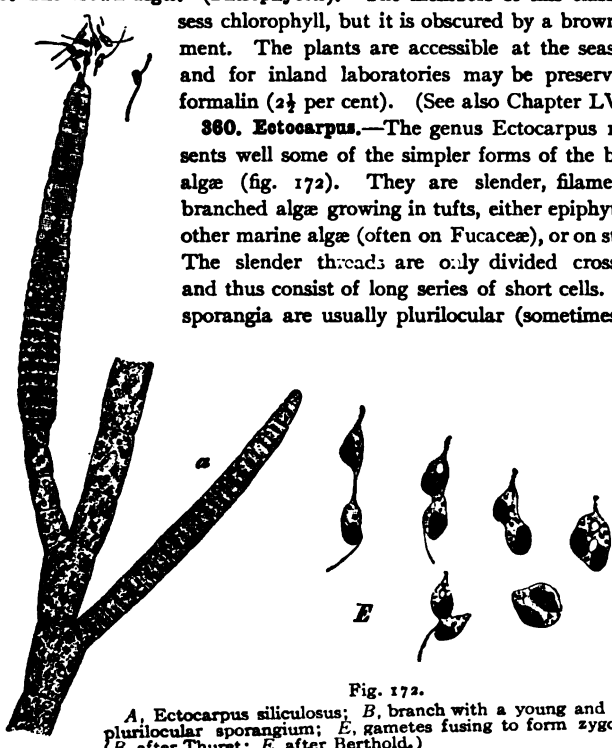

Fig. 172.

A, Ectocarpus siliculosus; *B*, branch with a young and a ripe plurilocular sporangium; *E*, gametes fusing to form zygospore. (*B*, after Thuret; *E*, after Berthold.)

locular), and usually occur in the place of lateral branches. The zoospores escape from the apex of the sporangium and are biciliate, and they fuse to form zygospores.

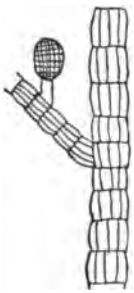

Fig. 173.
Sphacelaria, portion of plant showing longitudinal division of cells, and brood bud (pluriocular sporangium).

361. Sphacelaria.—The species of this genus represent an advance in the development of the thallus. While they are filamentous and branched, division takes place longitudinally as well as crosswise (fig. 173).

362. Leathesia difformis represents an interesting type because the plant body is small, globose, later irregular and hollow, and consists of short radiately arranged branches, the surface ones in the form of short, crowded, but free, trichome-like green branches. This trichothallic body recalls the similar form of Chætophora pisiformis (Chapter 16) among the Chlorophyceæ.

363. The Giant Kelps.—Among the brown algæ are found the largest specimens, some of the laminarias or giant kelps, rivaling in size the largest land plants, and some of them have highly developed tissues. *Postelsia palmæformis* has a long, stout stem, from the free end of which extend numerous large and long blades, while the stem is attached to the rocks by numerous "root" like outgrowths, the holdfasts. It occurs along the northern Pacific coast, and appears to flourish where it receives the shock of the surf beating on the shore. Several species of **Laminaria** occur on our north Atlantic coast. In **L. digitata,** the stem expands at the end into a broad blade, which becomes split into several smaller blades (fig. 174). *Macrocystis pyrifera* inhabits the ocean in the southern hemisphere, and sometimes is found along the north American coast. It is said to reach a length of 200–300 meters.

Fig. 174.
Laminaria digitata, forma cloustoni, North Sea. (Reduced.)

364. Fucus, or Rockweed.—This plant is a more or less branched and flattened thallus or "frond." One of them, illustrated in fig. 119, measures 15–30*cm* (6–12 inches) in length. It is attached to rocks and stones which are more or less exposed at low tide. From the base of the plant are developed several short and more or less branched expansions called "holdfasts," which, as their name implies, are organs of attachment. Some species (F. vesiculosus) have vesicular swellings in the thallus.

The fruiting portions are somewhat thickened as shown in the figure. Within these portions are numerous oval cavities opening by a circular pore, which gives a punctate appearance to these fruiting cushions. Tufts of hairs frequently project through them.

365. Structure of the conceptacles.—On making sections of the fruiting portions one finds the walls of the cavities covered with outgrowths. Some of these are short branches which bear a large rounded terminal sac, the

Fig. 175.
Portion of plant of Fucus showing conceptacles in enlarged ends; and below the vesicles (Fucus vesiculosus).

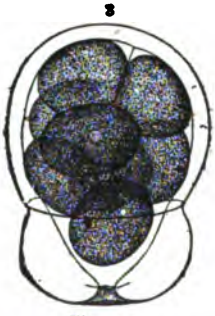

Fig. 177.
Oogonium of Fucus with ripe eggs.

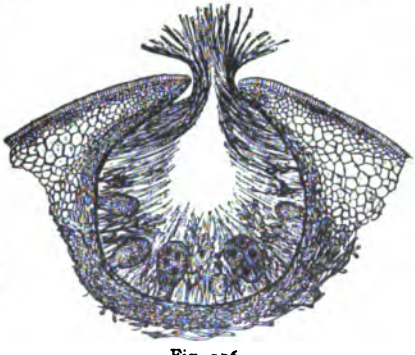

Fig. 176.
Section of conceptacle of Fucus, showing oogonia, and tufts of antheridia.

oogonium, at maturity containing eight egg cells. More slender and much-branched threads bear narrowly oval antheridia. In these are developed several two-ciliated spermatozoids.

366. Fertilization.—At maturity the spermatozoids and egg cells float outside of the oval cavities, where fertilization takes place. The spermatozoid

sinks into the protoplasm of the egg cell, makes its way to the nucleus of the egg, and fuses with it as shown in fig. 181. The fertilized egg then grows into a new plant. Nearly all the brown algæ are marine.

Fig. 178.
Antheridia of Fucus, on branched threads.

Fig. 179.
Antheridia of Fucus with escaping spermatozoids.

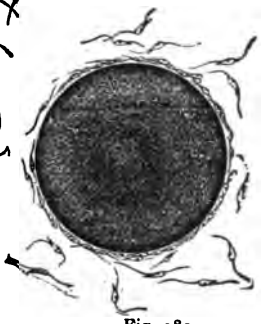

Fig. 180.
Eggs of Fucus surrounded by spermatozoids.

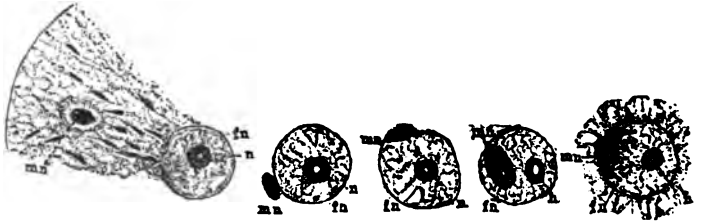

Fig. 181.
Fertilization in Fucus; *fn*, female nucleus; *mn*, male nucleus; *n*, nucleolus. In the left figure the male nucleus is shown moving down through the cytoplasm of the egg; in the remaining figures the cytoplasm of the egg is omitted. (After Strasburger.)

367. The Gulf weed (Sargassum bacciferum) in the warmer Atlantic ocean unites in great masses which float on the water, whence comes the name "Sargassum Sea." The Sargassum grows on the coast where it is attached to the rocks, but the beating of the waves breaks many specimens loose and these float out into the more quiet waters, where they continue to grow and multiply vegetatively.

368. Uses.—Laminaria japonica and L. angustata are used as food by the Chinese and Japanese. Some species of the Laminariaceæ are used as food for cattle and are also used for fertilizers, while L. digitata is sometimes employed in surgery.

Classification.—Kjellman divides the Phæophyceæ into two orders.

369. Order Phæosporales (Phæosporeæ) including 18 families. One of the most conspicuous families is the Laminariaceæ, including among others the Giant Kelps mentioned above (Laminaria, Postelsia, Macrocystis, etc.).

370. Order Cyclosporales (Cyclosporeæ).—This includes one family, the *Fucaceæ* with Ectocarpus, Sphacelaria, Læathesia, Fucus, Sargassum, etc.

Class Rhodophyceæ.

371. The red algæ (Rhodophyceæ).—The larger number of the so-called red algæ occur in salt water, though a few genera occur in fresh water. The plants possess chlorophyll, but it is usually obscured by a reddish or purple pigment.

372. Nemal on.—This is one of the lower marine forms, though its thallus is not one of the simplest in structure. The plant body consists of a slender cylindrical branched shoot, sometimes very profusely branched. The central strand is rather firm, while the cortex is composed of rather loose filaments.

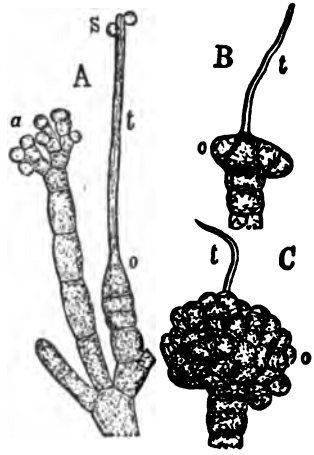

Fig. 182.

A red alga (Nemalion). *A*, sexual branches, showing antheridia (*a*); carpogonium or procarp (*o*) with its trichogyne (*t*), to which are attached two spermatia (*s*); *B*, beginning of a cystocarp (*o*), the trichogyne (*t*) still showing; *C*, an almost mature cystocarp (*o*), with the disorganizing trichogyne (*t*). (After Vines.)

373. Batrachospermum.—This genus occurs in fresh water, and the species are found in slow-running water of shallow streams or ditches. There is a central slender strand which is more or less branched, and on these branches are whorls of densely crowded slender branches occurring at regular intervals. The plants are usually very slippery. Gonidia are formed on the ends of some of these branches in globose, sporangia, called monosporangia, since but a single spore or gonidium is developed in each. Other branches often terminate in long slender hyaline setæ.

374. Lemanea.—This genus also occurs in fresh water. The species develop only during the cold winter months in rapids of streams or where the water from falls strikes the rocks and is thoroughly aerated. They form tufts of greenish threads, cylindrical or whiplike, which in the summer are usually much broken down. The threads are hollow and have a firm cortex. These are the sexual shoots,

and they arise as branches from a sterile filamentous-branched, Chantransia-like form.

375. Fertilization in the lower red algæ.—The sexual organs in the red algæ consist of antheridia and carpogonia. The antheridia are usually borne in crowded clusters, or surfaces, and bear terminally the small non-motile sperm cells. The carpogonium is a branch of one or several cells, the terminal cell (procarp) extending into a long slender process, the trichogyne. The sperm cell comes in contact with the trichogyne, and in the case of Nemalion and some others the nucleus has been found to pass down the inside and fuse with the nucleus of the procarp.

From this point in the lower red algæ like Nemalion, Batrachospermum

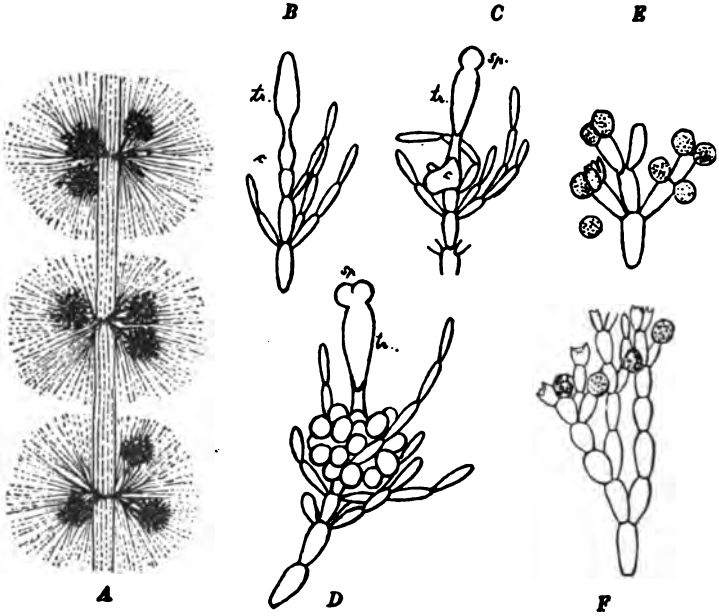

Fig. 183.

A, part of a shoot showing whorls of branches with clusters of carpospores. *B*, carpogonic branch or procarp: *c*, procarp cell; *tr*, trichogyne. *C*, same with sperm (*sp*) uniting with trichogyne. *D*, same with carpospores developing from procarp cell. *E*, male branch with one-celled antheridia. *F*, same with some of antheridia empty. (After Schmitz.)

and Lemanea the formation of the spores is very simple. The procarp is stimulated to growth, and buds in different directions, producing branched chains of spores (carpospores). The carpospores form a rather compact

cluster called the sporocarp, which means spore-fruit or spore-fruit body. In Batrachospermum it is seen as a compact tuft in the loose branching, in Nemalion it lies in the surface of the cortex, while in Lemanea the sporocarps lie at different positions in the hollow tube of the sexual shoot.

376. Gonidia in the red algæ.—The common type of gonidium in the red algæ is found in the *tetraspores*. A single mother cell divides into four cells arranged usually in the form of tetrads within the *tetrasporangium*. In Callithamnion the tetrasporangium is exposed. In Polysiphonia, Rhab-

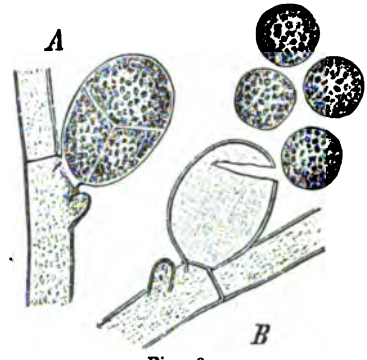

Fig. 184.
A red alga (Callithamnion), showing sporangium *A*, and the tetraspores discharged *B*. (After Thuret.)

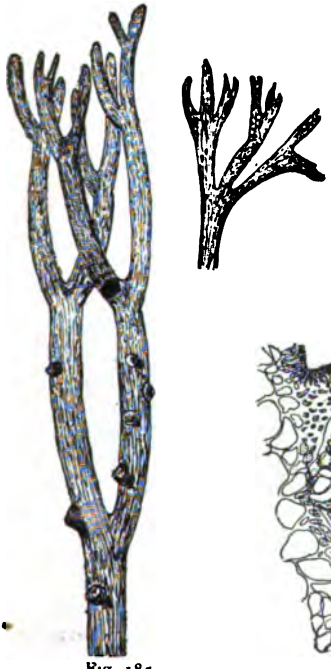

Fig. 185.
Gracilaria, portion of frond, showing position of cystocarps.

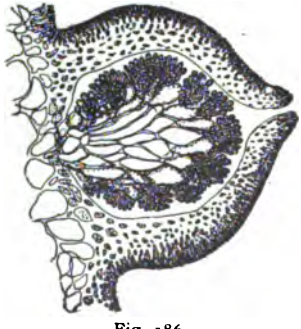

Fig. 186.
Gracilaria, section of cystocarp showing spores.

donia, Gracilaria, etc., it is imbedded in the cortex. In Batrachospermum there are monosporangia, each monosporangium containing a single gonidium, while in Lemanea, and according to some also in Nemalion, gonidia are wanting.

377. Gracilaria.—Gracilaria is one of the marine forms, and one species is illustrated in fig. 185. It measures 15–20*cm* or more long, and is profusely branched in a palmate manner. The parts of the thallus are more or less flattened. The fruit is a cystocarp, which is characteristic of the Rhodophyceæ (Florideæ). In Gracilaria these fruit bodies occur scattered over the thallus. They are somewhat flask-shaped, are partly sunk in the thallus, and the conical end projects strongly above the surface. The carpospores are grouped in radiating threads within the oval cavity of the cystocarp. These cystocarps are developed as a result of fertilization. Other plants bear gonidia in groups of four, the so-called *tetraspores*.

378. Rhabdonia.—This plant is about the same size as the gracilaria, though it possesses more filiform branches. The cystocarps form prominent elevations, while the carpospores lie in separated groups around the

Fig. 187.
Rhabdonia, branched portion of frond showing cystocarps.

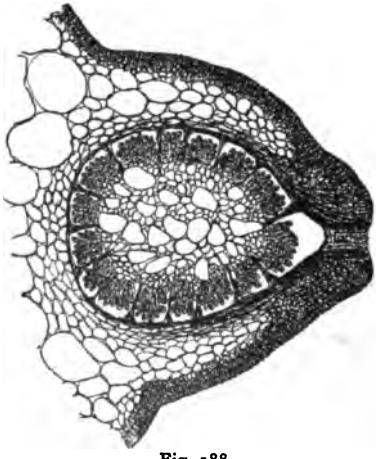

Fig. 188.
Section of cystocarp of rhabdonia, showing spores.

periphery of a sterile tissue within the cavity. (See figs. 187, 188.) Gonidia in the form of tetraspores are also developed in Rhabdonia.

379. Fertilization of the higher red algæ.—The process of fertilization in most of the red algæ is very complicated, chiefly because the fertilized egg cell (procarp) does not develop the spores directly, as in Nemalion, Le-

manea, etc., but fuses directly, or by a short cell or long filament with one or more auxiliary cells before the sporocarp is finally formed. Examples are Rhabdonia, Polysiphonia, Callithamnion, Dudresnaya, etc. (fig. 189). The auxiliary cell then develops the sporocarp. See fig. 189 for conjugation of a filament from the fertilized procarp with an auxiliary cell.

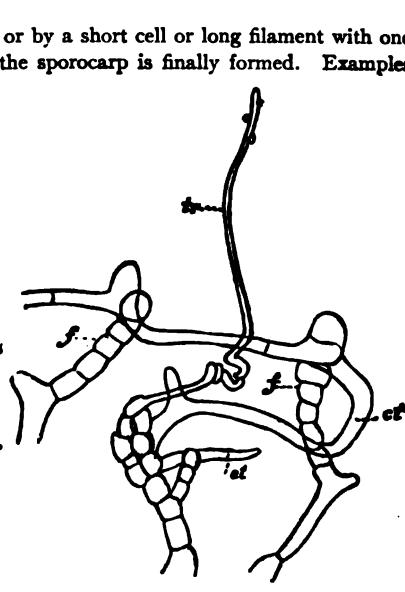

Fig. 189.

Dudresnaya purpurifera. *tr*, trichogyne, with sperm cells attached. *ct*, connecting-tube which grows out from below the base of the trichogyne, and comes in contact with the fertile branches *f*, *f*; *ct'*, young connecting-tube. (After Thuret and Bornet.)

380. Uses of the red algæ.—Many species produce a great amount of gelatinous substance in their tissues, and several of these are used for food, for the manufacture of gelatines and agar-agar. Some of these are Gracilaria lichenoides and wrightii, the former species occurring along the coast of India and China. The plant is easily converted into gelatinous substance (agar-agar). Chondrus crispus, widely distributed in the northern Atlantic is known as "Irish" moss and is used for food and for certain medicinal purposes. Gigartina mamillosa in the Atlantic and Arctic oceans is similarly employed. The following orders are recognized in the red algæ:

381. Order Bangiales.—Example, Bangia atropurpurea (= Conferva atropurpurea) in springs and brooks in North America and Europe. Porphyra contains a number of species forming broad, thin, leaf-like purple sheets in the sea.

382. Order Nemalionales. — Including Lemanea, Batrachospermum, Nemalion, described above, and many others.

383. Order Gigartinales.—In this order occurs the common Iceland moss (Chondrus crispus) in the sea, and Rhabdonia and Gigartina mentioned above.

384. Order Rhodomeniales.—In this order occurs Gracilaria and Polysiphonia mentioned above, also the beautiful marine forms like Ceramium.

385. Order Cryptonemiales. — Examples are Dudresnaya, Melobesia, Corallina, etc., the last two genera include many species with a wide distribution.

Class Charophyceæ, Order Charales.

386. The Charales are by some thought to represent a distinct class of algæ standing near the mosses, perhaps, because of the biciliate character of the spermatozoids. There is one family, the Characeæ. The plants occur in fresh and brackish water. Aside from the peculiarity of the reproductive organs they are remarkable for the large size of the cells of the internodes and of the "leaves," and the protoplasm exhibits to a remarkable degree the phenomenon of "cyclosis" (see paragraphs 17–20). Three of the genera are found in North America (Chara, Nitella (Fig. 8) and Tolypella).

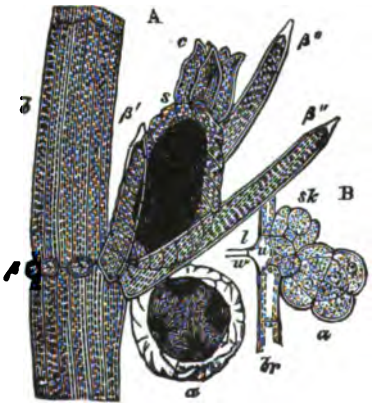

Fig. 172a.

Reproductive organs of *Chara fragilis*. *A*, a central portion of a leaf, *b*, with an antheridium, *a*, and a carpogonium, *s*, surrounded by the spirally twisted enveloping cells; *c*, crown of five cells at apex; *β*, sterile lateral leaflets; *β'*, large lateral leaflet near the fruit; *β''*, bracteoles springing from the basal node of the reproductive organs. *B*, a young antheridium, *a*, and a young carpogonium, *sk*; *w*, nodal cell of leaf; *u*, intermediate cell between *w* and the basal-node cell of the antheridium; *l*, cavity of the internode of the leaf; *br*, cortical cells of the leaf. *A* × about 33; *B* × 240. (After Sachs.)

386a. The complicated structure of the sexual organs shows a higher state of organization than any of the other living algæ known. While the internodes in Nitella are composed of a single, stout cell, some times a foot or more in length, the nodes in all are composed of a group of smaller cells. From the lateral cells of this group lateral axes (sometimes called leaves) arise in whorls.

In Nitella the internodes are naked, but in most species of Chara they are *corticated*, i.e., they are covered by a layer of numerous elongated cells which grow downward from the nodes at the base of the whorl of lateral shoots.

386b. The sexual organs are situated at the nodes of the whorled lateral shoots, and consist of antheridia and carpogonia. Most of the plants are monœcious, and both antheridia and carpogonia are often attached to the same node, the antheridium projecting downward while the carpogonium is more or less ascending. The sexual organs are visible to the unaided eye. The antheridium is a globose red body of an exceedingly complicated structure. The sperms are borne in several very long coiled slender threads which are divided transversely into numerous cells. The carpogonium is oval or elliptical in outline, the wall of which is composed of several closely coiled spiral threads enclosing the large egg.

CHAPTER XIX.

FUNGI: MUCOR AND SAPROLEGNIA.

Mucor.

387. In the chapter on growth, and in our study of protoplasm, we have become familiar with the vegetative condition of mucor. We now wish to learn how the plant multiplies and reproduces itself. For this study we may take one of the mucors. Any one of several species will answer. This plant may be grown by placing partially decayed fruits, lemons, or oranges, from which the greater part of the juice has been removed, in a moist chamber; or often it occurs on animal excrement when placed under similar conditions. In growing the mucor in this way we are likely to obtain Mucor mucedo, or another plant sometimes known as Mucor stolonifer, or Rhizopus nigricans, which is illustrated in fig. 191. This latter one is sometimes very injurious to stored fruits or vegetables, especially sweet potatoes or rutabagas. Fig. 190 is from a photograph of this fungus on a banana.

388. Asexual reproduction.—On the decaying surface of the vegetable matter where the mucor is growing there will be seen numerous small rounded bodies borne on very slender stalks. These heads contain the gonidia, and if we sow some of them in nutrient gelatine or agar in a Petrie dish the material can be taken out very readily for examination under the microscope. Or we may place glass slips close to the growing fungus in the moist chamber, so that the fungus will develop on them, though cultures in a nutrient medium are much better. Or we may take the material directly from the substance on which it is growing.

After mounting a small quantity of the mycelium bearing these heads, if we have been careful to take it where the heads appear quite young, it may be possible to study the early stages of their

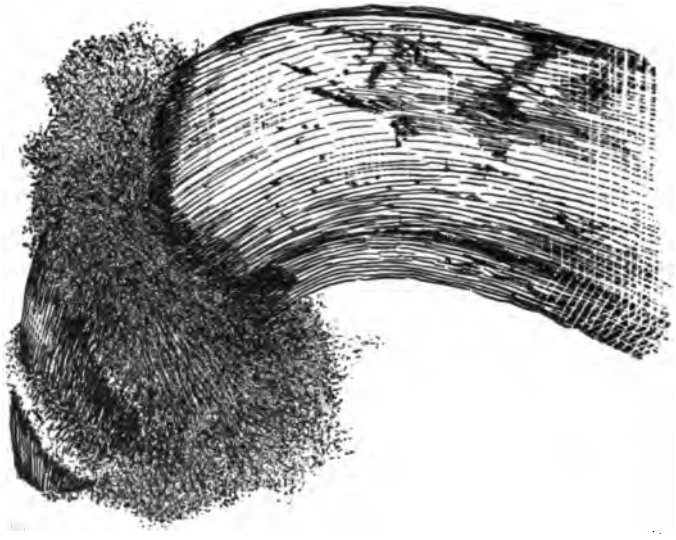

Fig. 190.
Portion of banana with a mould (Rhizopus nigricans) growing on one end.

development. We shall probably note at once that the stalks or upright threads which support the heads are stouter than the threads of the mycelium.

These upright threads soon have formed near the end a cross wall which separates the protoplasm in the end from the remainder. This end cell now enlarges into a vesicle of considerable size, the head as it appears, but to which is applied the name of *sporangium* (sometimes called gonidangium), because it encloses the *gonidia*.

At the same time that this end cell is enlarging the cross wall is arching up into the interior. This forms the *columella*. All the protoplasm in the sporangium now divides into gonidia. These are small rounded or oval bodies. The wall of the spo-

rangium becomes dissolved, except a small collar around the stalk which remains attached below the columella (fig. 192).

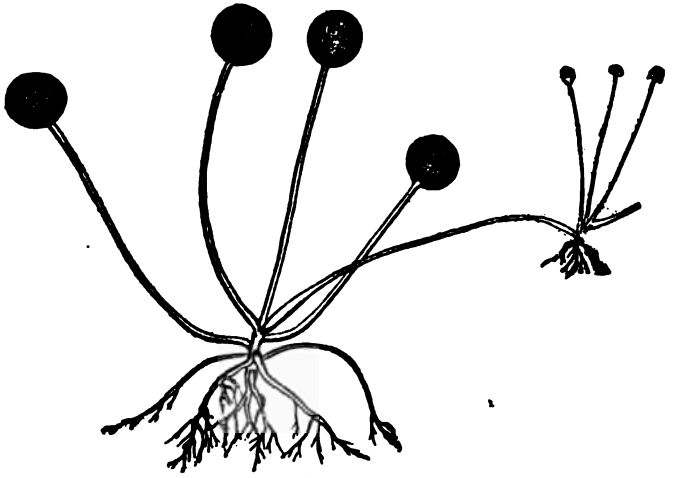

Fig. 191.
Group of sporangia of a mucor (Rhizopus nigricans) showing rhizoids and the stolon extending from an older group.

By this means the gonidia are freed. These gonidia germinate and produce the mycelium again.

389. Sexual stage.—This stage is not so frequently found, but may sometimes be obtained by growing the fungus on bread.

Conjugation takes place in this way. Two threads of the mycelium which lie near each other put out each a short branch which is clavate in form. The ends of these branches meet, and in each a septum is formed which cuts off a portion of the protoplasm in the end from that of the rest of the mycelium. The meeting walls of the branches now dissolve and the protoplasm of each gamete fuses into one mass. A thick wall is now formed around this mass, and the outer layer becomes rough and brown. This is the *zygote* or *zygospore*. The mycelium dies and it becomes free often with the suspensors, as the stalks of these sexual branches are called, still attached. This zygospore passes through a period of rest, when with the entrance of favorable conditions of growth it germinates, and usually produces directly a sporangium with gonidia. This completes the normal life cycle of the plant.

390. Gemmæ.—Gemmæ, as they are sometimes called, are often formed on the mycelium. A short cell with a stout wall is formed on the side of a

thread of the mycelium. In other cases large portions of the threads of the mycelium may separate into chains of cells. Both these kinds of cells are

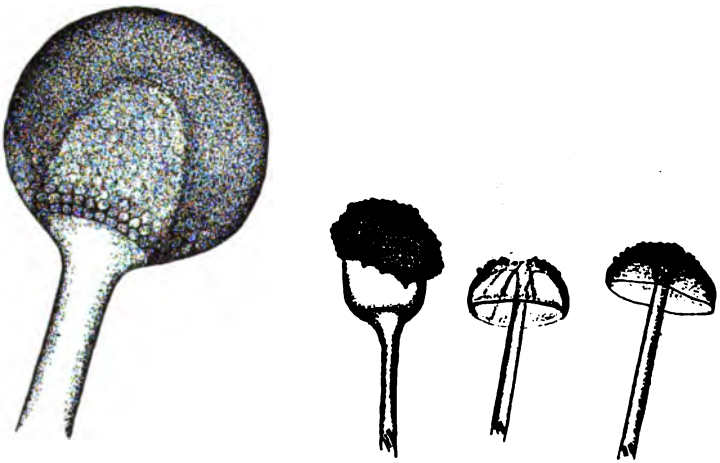

Fig. 194.

A mucor (Rhizopus nigricans); at left nearly mature sporangium with columella showing within; in the middle is ruptured sporangium with some of the gonidia clinging to the columella; at right two ruptured sporangia with everted columella.

capable of growing and forming the mycelium again. They are sometimes called *chlamydospores*.

390*a*. **The** Mucorineæ according to their manner of zygospore formation are of two kinds: 1st, the ***homothallic*** (monœcious), in which all of the colonies or thalli developed from different spores are the same, and both gametes may be developed from the mycelium from a single spore, as in Sporodinia grandis, a mould common on old mushrooms; 2d, the ***heterothallic*** (diœcious), in which certain plants are of a male nature and small in comparison with those of perhaps a female nature which are larger or more vigorous. When grown separately each of these two kinds of thalli, or colonies of mycelium, produce their own kind but only sporangia. If the two kinds are brought together, however, branches from one conjugate with branches from the other and zygospores are produced, as in Rhizopus nigricans, the common bread or fruit mould. This is one reason why we rarely find this fungus forming zygospores. (See Blakeslee, Sexual Reproduction in the Mucorineæ, Proc. Am. Acad. Arts and Sci., **40**, 205–319, pl. 1–4, 1904.)

Water Moulds (Saprolegnia).

391. The water moulds are very interesting plants to study because they are so easy to obtain, and it is so easy to observe a type of gonidium here to which we have referred in our studies of the algæ, the motile gonidium, or zoogonidium. (See appendix for directions for cultivating this mould.)

392. Appearance of the saprolegnia.—In the course of a few days we are quite certain to see in some of the cultures delicate whitish threads, radiating outward from the body of the fly in the water. A few threads should be examined from day to day to determine the stage of the fungus.

393. Sporangia of saprolegnia.—The sporangia of saprolegnia can be easily detected because they are much stouter than the ordinary threads of the mycelium. Some of the threads should be mounted in fresh water. Search for some of those which

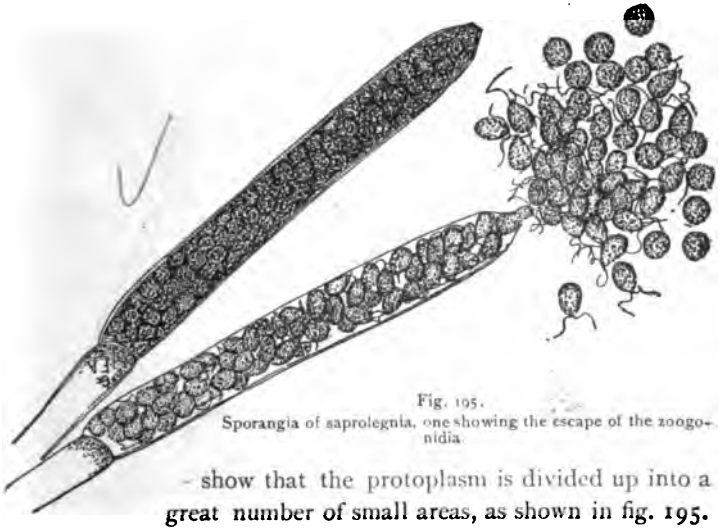

Fig. 195.
Sporangia of saprolegnia, one showing the escape of the zoogonidia.

show that the protoplasm is divided up into a great number of small areas, as shown in fig. 195.

With the low power we should watch some of the older appearing ones, and if after a few minutes they do not open, other preparations should be made.

394. Zoogonidia of saprolegnia.—The sporangium opens at

Fig. 196.
Branch of saprolegnia showing oogonia with oospores, eggs matured parthenogenetically.

the end, and the zoogonidia swirl out and swim around for a short time, when they come to rest. With a good magnifying

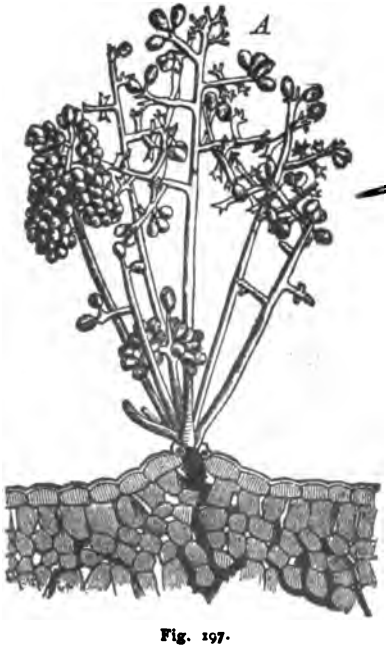

Fig. 197.
Downy mildew of grape (Plasmopora viticola), showing tuft of gonidiophores bearing gonidia, also intercellular mycelium. (After Millardet.)

Fig. 198.
Phytophthora infestans showing peculiar branches; gonidia below.

power the two cilia on the end may be seen, or we may make

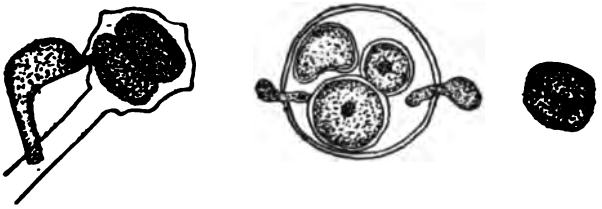

Fig. 199.

Fertilization in saprolegnia, tube of antheridium carrying in the nucleus of the sperm cell to the egg. In the right-hand figure a smaller sperm nucleus is about to fuse with the nucleus of the egg. (After Humphrey and Trow.)

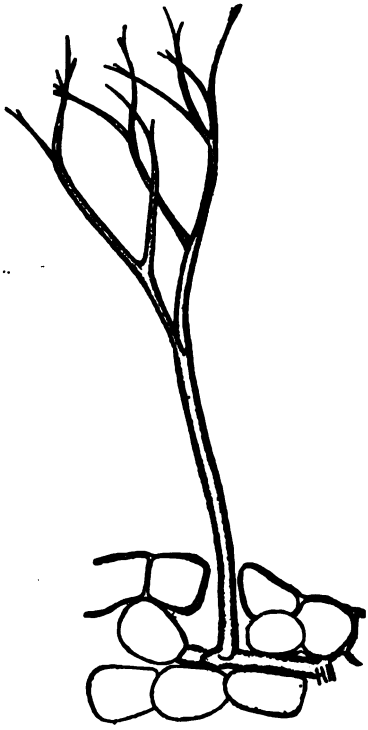

Fig. 200.

Branching hypha of Peronospora alsinearum.

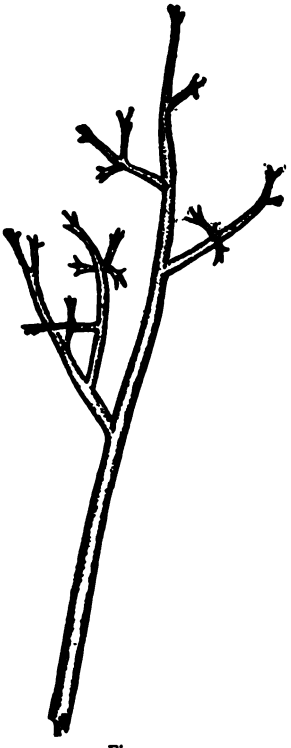

Fig. 201.

Branched hypha of downy mildew of grape showing peculiar branching (*Plasmopara viticola*).

them more distinct by treatment with Schultz's solution, drawing some under the cover glass. The zoogonidium is oval and the cilia are at the pointed end. After they have been at rest for some time they often slip out of the thin wall, and swim again, this time with the two cilia on the side, and then the zoogonidium is this time more or less bean-shaped or reniform.

395. Sexual reproduction of saprolegnia.—When such cultures are older we often see large rounded bodies either at the end of a thread, or of a branch, which contain several smaller rounded bodies as shown in fig. 196. These are the oogonia (unless the plant is attacked by a parasite), and the round bodies inside are the egg cells, if before fertilization, or the eggs, if after this process has taken place. Sometimes the slender antheridium can be seen coiled partly around the oogonium, and one end entering to come in contact with the egg cell. But in some species the antheridium is not present, and that is the case with the species figured at 196. In this case

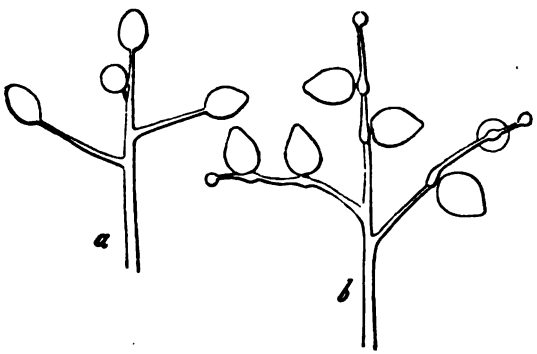

Fig. 202.

Gonidiophores and gonidia of potato blight (Phytophthora infestans). *b*, an older stage showing how the branch enlarges where it grows beyond the older gonidium. (After de Bary.)

Fig. 203.

Gonidia of potato blight forming zoogonidia. (After de Bary.)

the eggs mature without fertilization. This maturity of the egg without fertilization is called *parthenogenesis*, which occurs in other plants also, but is a rather rare phenomenon.

396. In fig. 199 is shown the oogonium and an antheridium, and the antheridium is carrying in the male nucleus to the egg cell. Spermatozoids are not developed here, but a nucleus in the antheridium reaches the egg cell. It sinks in the protoplasm of the egg, comes in contact with the nucleus of the egg, and fuses with it. Thus fertilization is accomplished.

Downy Mildews.

397. The downy mildews make up a group of plants which are closely related to the water moulds, but they are parasitic on land plants, and some species produce very serious diseases. The mycelium grows between the

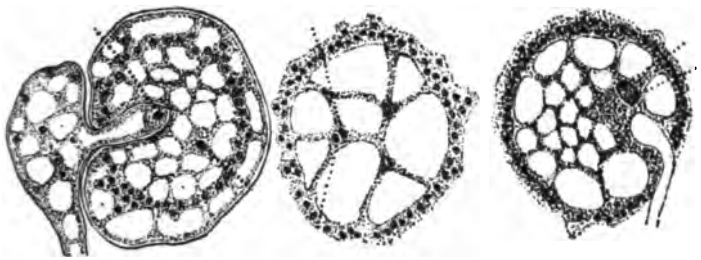

Fig. 204.

Fertilization in Peronospora alsinearum; tube from antheridium carrying in the sperm nucleus in figure at the left, female nucleus near; fusion of the two nuclei shown in the two other figures. (After Berlese.)

cells of the leaves, stems, etc., of their hosts, and sends haustoria into the cells to take up nutriment. Gonidia are formed on threads which grow through the stomates to the outside and branch as shown in figs. 198–201. The gonidia are borne on the tips of the branches. The kind of branching bears some relation to the different genera. Fig. 200 is from Peronospora alsinearum on leaves of cerastium; figs. 197 and 199 are Plasmopara viticola, the grape mildew, while figs. 198 and 202 are from Phytophthora infestans which causes a disease known as potato blight. The gonidia of peronospora germinate by a germ tube, those of plasmopara first form zoogonidia, while in phytophthora the gonidium may either germinate forming a thread, or each gonidium may first form several zoogonidia, as shown in fig. 203.

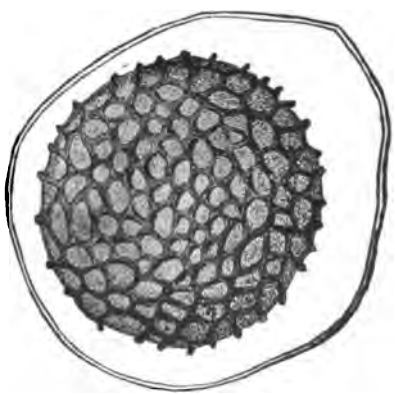

Fig. 205.
Ripe oospore of Peronospora alsinearum.

398. In sexual reproduction oogonia and antheridia are developed on the mycelium within the tissues. Fig. 204 represents the antheridium enter-

ing the oogonium, and the male nucleus fusing with the female nucleus in fertilization. The sexual organs of Phytophthora infestans are not sufficiently known.

399. Mucor, saprolegnia, peronospora, and their relatives have few or no septa in the mycelium. In this respect they resemble certain of the algæ like vaucheria, but they lack chlorophyll. They are sometimes called the alga-like fungi and belong to a large group called *Phycomycetes*.

CHAPTER XX.

FUNGI CONTINUED.

"Rusts" (Uredineæ).

400. The fungi known as "rusts" are very important ones to study, since all the species are parasitic, and many produce serious injuries to crops.

401. Wheat rust (Puccinia graminis).—The wheat rust is one of the best known of these fungi, since a great deal of study has been given to it. One form of the plant occurs in long

Fig. 206. Wheat leaf with red rust, natural size.

Fig. 207. Portion of leaf enlarged to show sori.

Fig. 208. Natural size.

Fig. 209. Enlarged.

Fig. 210. Single sorus.

Figs. 206, 207.—Puccinia graminis, red-rust stage (uredo stage).
Figs. 208–210.—Black rust of wheat, showing sori of teleutospores.

reddish-brown or reddish pustules, and is known as the "red rust" (figs. 206, 207). Another form occurs in elongated black pustules, and this form is the one known as the "black rust"

(figs. 208–211). These two forms occur on the stems, blades, etc., of the wheat, also on oats, rye, and some of the grasses.

402. Teleutospores of the black-rust form.—If we scrape off some portion of one of the black pustules (sori), tease it out

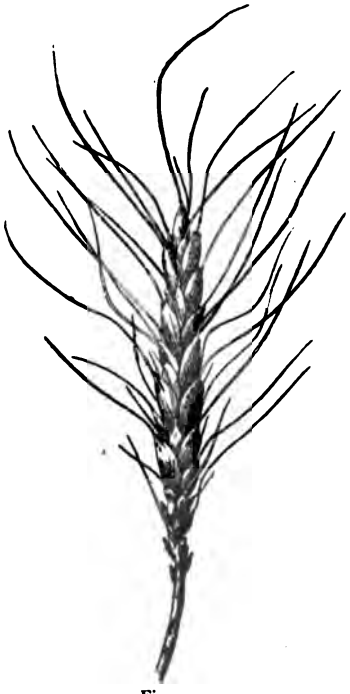

Fig. 211.
Head of wheat showing black rust spots on the chaff and awns.

Fig. 212.
Teleutospores of wheat rust, showing two cells and the pedicel.

Fig. 213.
Uredospores of wheat rust, one showing remnants of the pedicel.

in water on a slide, and examine with a microscope, we see numerous gonidia, composed of two cells, and having thick, brownish walls as shown in fig. 212. Usually there is a slender brownish stalk on one end. These gonidia are called *teleutospores*. They are somewhat oblong or elliptical, a little constricted where the septum separates the two cells, and the end cell varies from ovate to rounded. The mycelium of the fungus

courses between the cells, just as is found in the case of the carnation rust, which belongs to the same family (see Parag. 186).

403. Uredospores of the red-rust form.—If we make a similar preparation from the pustules of the red-rust form we see that instead of two-celled gonidia they are one-celled. The walls are thinner and not so dark in color, and they are covered with minute spines. They have also short stalks, but these fall away very easily. These one-celled gonidia of the red-rust form are called "uredospores." The uredospores and teleutospores are sometimes found in the same pustule.

It was once supposed that these two kinds of gonidia belonged to different plants, but now it is known that the one-celled form, the uredospores, is a form developed earlier in the season than the teleutospores.

404. Cluster-cup form on the barberry.—On the barberry is found still another form of the wheat rust, the "*cluster cup*" stage. The pustules on the under side of the barberry leaf are cup-shaped, the cups being partly sunk in the tissue of the leaf, while the rim is more or less curved backward against the leaf, and split at several places. These cups occur in clusters on the affected spots of the barberry leaf as shown in fig. 215. Within the cups numbers of one-celled gonidia (orange in color, called æcidiospores) are borne in chains from short branches of the mycelium, which fill the base of the cup. In fact the wall of the cup (peridium)

Fig. 214. Barberry leaf with two diseased spots, natural size.

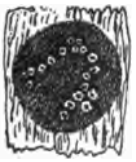

Fig. 215. Single spot showing cluster cups enlarged.

Fig. 216. Two cluster cups more enlarged, showing split margin.

Figs. 214–216.—Cluster-cup stage of wheat rust.

is formed of similar rows of cells, which, instead of separating into gonidia, remain united to form a wall. These cups are usually borne on the under side of the leaf.

405. Spermagonia.—Upon the upper side of the leaves in the same spot occur small, orange-colored pustules which are flask-shaped. They bear inside, minute, rod-like bodies on the ends of slender threads, which ooze

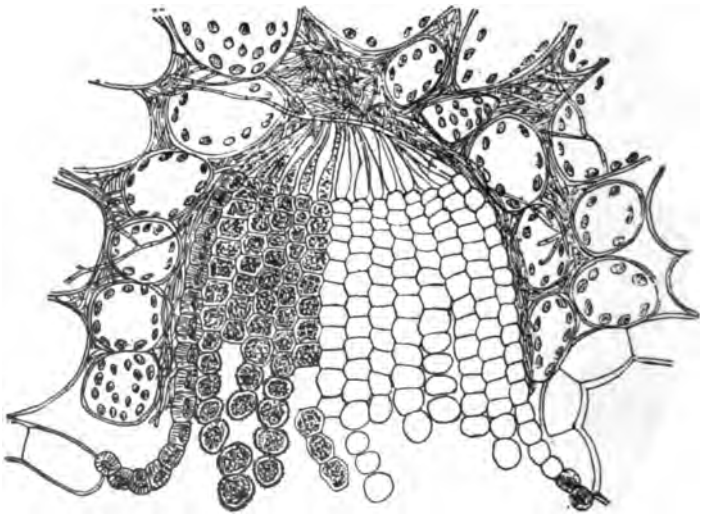

Fig. 217.
Section of an æcidium (cluster cup) from barberry leaf. (After Marshall-Ward.)

out on the surface of the leaf. These flask-shaped pustules are called *spermagonia*, and the minute bodies within them *spermatia*, since they were once supposed to be the male element of the fungus. Their function is not known. They appear in the spots at an earlier time than the cluster cups.

406. How the cluster-cup stage was found to be a part of the wheat rust.—The cluster-cup stage of the wheat rust was once supposed also to be a different plant, and the genus was called *æcidium*. The occurrence of wheat rust in great abundance on the leeward side of affected barberry bushes in England suggested to the farmers that wheat rust was caused by barberry rust. It was later found that the æcidiospores of the barberry, when sown on wheat, germinate and the thread of mycelium enters the tissues of the wheat, forming mycelium between the cells. This mycelium then bears the uredospores, and later the teleutospores.

407. Uredospores can produce successive crops of uredospores.—The uredospores are carried by the wind to other wheat or grass plants, germinate

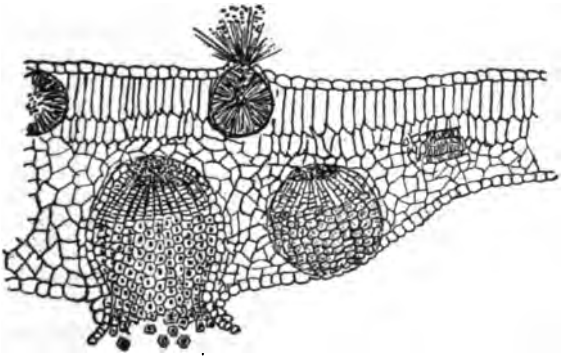

Fig. 218.

Section through leaf of barberry at point affected with the cluster-cup stage of the wheat rust; spermagonia above, æcidia below. (After Marshall-Ward.)

form mycelium in the tissues, and later the pustules with a second crop of uredospores. Several successive crops of uredospores may be developed in

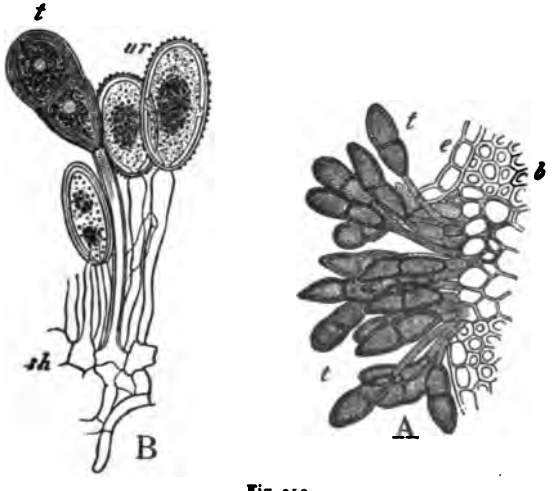

Fig. 219.

A, section through sorus of black rust of wheat, showing teleutospores. *B*, mycelium bearing both teleutospores and uredospores. (After de Bary.)

one season, so this is the form in which the fungus is greatly multiplied and widely distributed.

407a. Teleutospores the last stage of the fungus in the season.—The teleutospores are developed late in the season, or late in the development of the host plant (in this case the wheat is the host). They then rest during the winter. In the spring under favorable conditions each cell of the teleutospore germinates, producing a short mycelium called a *promycelium*, as shown in figs. 222, 223. This promycelium is usually divided into four cells. From each cell a short, pointed process is formed called a "*sterigma*." Through this the protoplasm moves and forms a small gonidium on the end, sometimes called a *sporidium*.

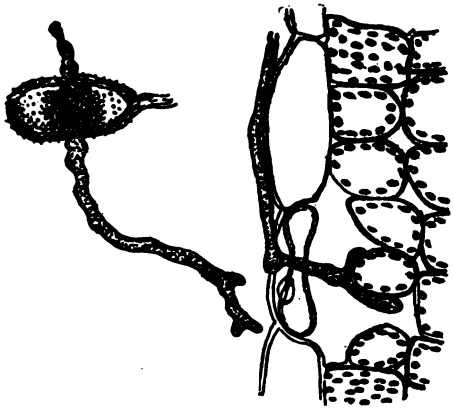

Fig. 220. Germinating uredospore of wheat rust. (After Marshall-Ward.)

Fig. 221. Germ tube entering the leaf through a stoma.

408. How the fungus gets from the wheat back to the barberry.—If these sporidia from the teleutospores are carried by the wind so that they lodge on

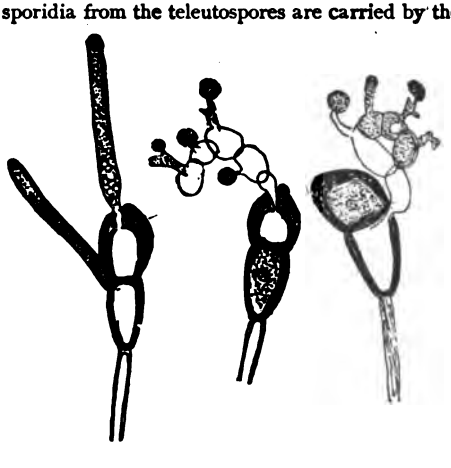

Fig. 222. Teleutospore germinating, forming promycelium.

Fig. 223. Promycelium of germinating teleutospore, forming sporidia.

Fig. 224. Germinating sporidia entering leaf of barberry by mycelium.

Figs. 222–224.—Puccinia graminis (wheat rust). (After Marshall-Ward.)

the leaves of the barberry, they germinate and produce the cluster cup again. The plant has thus a very complex life history. Because of the presence of several different forms in the life cyle, it is called a *polymorphic* fungus.

The presence of the barberry does not seem necessary in all cases for the development of the fungus from one year to another.

409. Synopsis of life history of wheat rust.

Cluster-cup stage on leaf of barberry.

Mycelium between cells of leaf in affected spots.

Spermagonia (sing. spermagonium), small flask-shaped bodies sunk in upper side of leaf; contain "spermatia."

Æcidia (sing. æcidium), cup-shaped bodies in under side of leaf.

Wall or peridium, made up of outer layer of fungus threads which are divided into short cells but remain united.

At maturity bursts through epidermis of leaf; margin of cup curves outward and downward toward surface of leaf.

Central threads of the bundle are closely packed, but free. Threads divide into short angular cells which separate and become æcidiospores, with orange-colored content.

Æcidiospores carried by the wind to wheat, oats, grasses, etc. Here they germinate, mycelium enters at stomate, and forms mycelium between cells of the host.

Uredo stage (red rust) on wheat, oats, grasses, etc.

Mycelium between cells of host.

Bears uredospores (1-celled) in masses under epidermis, which is later ruptured and uredospores set free.

Uredospores carried by wind to other individual hosts, and new crops of uredospores formed.

Teleutospore stage (black rust), also on wheat, etc.

Mycelium between cells of host.

Bears teleutospores (2-celled) in masses (sori) under epidermis, which is later ruptured.

Teleutospores rest during winter. In spring each cell germinates and produces a promycelium, a short thread, divided into four cells.

Promycelium bears four sterigmata and four gonidia (or sporidia), which in favorable conditions pass back to the barberry, germinate, the tube enters between cells into the intercellular spaces of the host to produce the cluster cup again, and thus the life cycle is completed.

410. Other examples of the rusts.—Some of the rusts do great injury to fruit trees and also to forest trees. The "cedar apples" are abnormal growths on the leaves and twigs of the cedar stimulated by the presence of the mycelium of a rust known as Gymnosporangium macropus. The teleutospores are two celled and are formed in the tissue of the "cedar apple" or gall. The teleutosori are situated at quite regular intervals over the surface of the gall at small circular depressions, and can be easily seen in late autumn and during the winter. A quantity of gelatine is developed along with the teleutospores. In early spring with the warm spring rains the gelatinous substance accompanying the teleutospores swells greatly, and causes the teleutospores to ooze out in long, dull, orange-colored strings, which taper gradually to a slender point and bristle all over the "cedar apple." Here the teleutospores germinate and produce the sporidia. The sporidia are carried to apple trees where they infect leaves and even the fruit, producing here the cluster cups. There are no uredospores.

G. globosum is another species forming cedar apples, but the gelatinous strings of teleutospores are short and clavate, and the cluster cups are formed on hawthorns. G. nidusavis forms "witches brooms" or "birds nests" in the branches of the cedar. The mycelium in the branches stimulates them to profuse branching so that numerous small branches are developed close together. The teleutosori form small pustules scattered over the branches. G. clavipes affects the branches of cedar only slightly deforming them or not at all, and the cluster cups are formed on fruits, twigs, and leaves of the hawthorns or quinces, the cluster cups being long, tubular, and orange in color.

CHAPTER XXI.

THE HIGHER FUNGI.

411. The series of the higher fungi.—Of these there are two large series. One of these is represented by the sac fungi, and the other by the mushrooms, a good example of which is the common mushroom (Agaricus campestris).

Sac Fungi (Ascomycetes).

412. The sac fungi may be represented by the "powdery mildews"; examples, uncinula, microsphæra, podosphæra, etc. Fig. 225 is from a photograph of two willow leaves affected by one of these mildews. The leaves are first partly covered with a whitish growth of mycelium, and numerous chains of colorless gonidia are borne on short erect threads. The masses of gonidia give the leaf a powdery appearance. The mycelium lives on the outer surface of the leaf, but sends short haustoria into the epidermal cells.

413. Fruit bodies of the willow mildew.—On this same mycelium there appear later numerous black specks scattered over the affected places of the leaf. These are the fruit bodies (*perithecia*). If we scrape some of these from the leaf, and mount them in water for microscopic examination, we shall be able to see their structure. Examining these first with a low power of the microscope, each one is seen to be a rounded body, from which radiate numerous filaments, the *appendages*. Each one of these appendages is coiled at the end into the form of a little hook. Because of these hooked appendages this genus is called *uncinula*. This rounded body is the *perithecium*.

414. Asci and ascospores.—While we are looking at a few of these through the microscope with the low power, we should

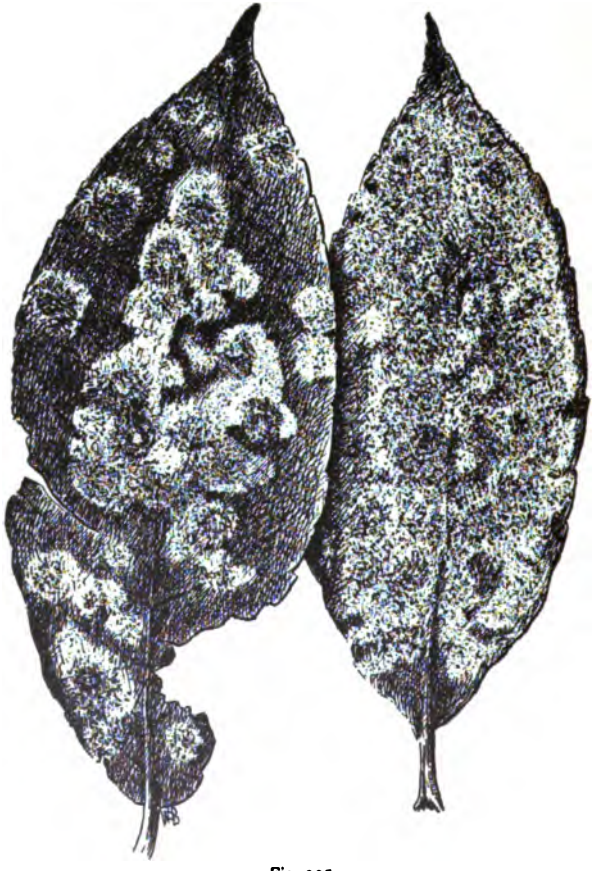

Fig. 225.
Leaves of willow showing willow mildew. The black dots are the fruit bodies (perithecia) seated on the white mycelium.

press on the cover glass with a needle until we see a few of the perithecia rupture. If this is done carefully we see several small ovate sacs issue, each containing a number of spores, as shown in fig. 227. Such a sac is an *ascus*, and the spores are *ascospores*.

415. Number of spores in an ascus.—The ascus is the most important character showing the general relationship of the members of the sac fungi.

Fig. 226.

Willow mildew; bit of mycelium with erect conidiophores, bearing chain of gonidia; gonidium at left germinating.

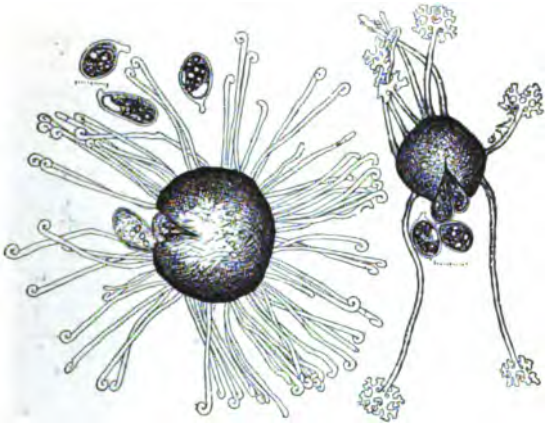

Fig. 227.

Fruit of willow mildew, showing hooked appendages. Genus uncinula.

Figs. 227 228.—Perithecia (perithecium) of two powdery mildews, showing escape of asci containing the spores from the crushed fruit bodies.

Fig. 228.

Fruit body of another mildew with dichotomous appendages. Genus microsphæra.

While many of the powdery mildews have a variable number of spores in

Fig. 229.

Contact of antheridium and carpogonium (carpogonium the larger cell); beginning of fertilization.

Fig. 230.

Disappearance of contact walls of antheridium and carpogonium, and fusion of the two nuclei.

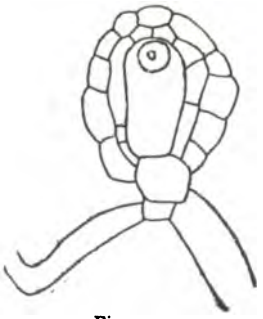

Fig. 231.

Fertilized egg surrounded by the enveloping threads which grow up around it.

Figs. 229–231.—Fertilization in sphærotheca; one of the powdery mildews. (After Harper.)

an ascus, a large majority of the ascomycetes have just 8 spores in an

ascus, while some have 4, others 16, and some an indefinite number. The asci in a perithecium are more variable. In some ascomycetes there is no perithecium.

416. The black fungi.—These are very common on dead logs, branches,

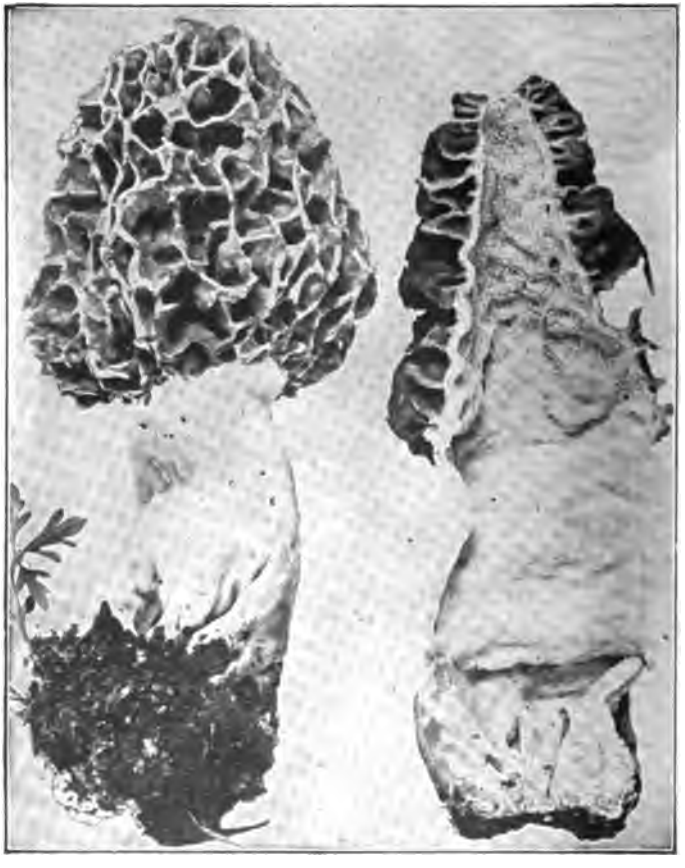

Fig. 231*a*.

Edible Morel. Morchella esculenta. The asci, forming hymenium, cover the pitted surface.

leaves, etc., and may be collected in the woods at almost any season. The perithecia are often numerous, scattered or densely crowded as in Rosel-

linia. Sometimes they are united to form a crust which is partly formed from sterile elements as in Hypoxylon, or they form black clavate or branched bodies as in Xylaria. The black knot of the plum and cherry is also an example.

The lichens are mostly ascomycetes like the black fungi or cup fungi, while a few are basidiomycetes.

417. The morels (Morchella).—There are several species of morels which are common in early spring on damp ground. Either one of the species is suitable for use if it is desired to include this in the study. Fig. 231*a* illustrates the Morchella esculenta. The stem is cylindrical and stout. The fruiting portion forms the "head," and it is deeply pitted. The entire pitted surface is covered by the asci, which are cylindrical and eight spored. A thin section may be made of a portion for study, or a small piece may be crushed under the cover glass.

418. The cup fungi.—These fungi are common on damp ground or on rotting logs in the summer. They may be preserved in 70 per cent alcohol for study. Many of them are shaped like broad open cups or saucers. The inner surface of the cup is the fruiting surface, and is covered with the cylindrical asci, which stand side by side. A bit of the cup may be sectioned or crushed under a cover glass for study.

Mushrooms (Basidiomycetes).

419. The large group of fungi to which the mushroom belongs is called the basidiomycetes because in all of them a structure resembling a club, or basidium, is present, and bears a limited number of spores, usually four, though in some genera the number is variable. Some place the rusts (Uredineæ) in the same series (basidium series), because of the short promycelium and four sporidia developed from each cell of the teleutospore.

420. The gill-bearing fungi (Agaricaceæ).—A good example for this study is the common mushroom (Agaricus campestris).

This occurs from July to November in lawns and grassy fields. The plant is somewhat umbrella-shaped, as shown in fig. 232, and possesses a cylindrical stem attached to the under side of the convex cap or pileus. On the under side of the pileus are thin radiating plates, shaped somewhat like a knife blade. These are the gills, or lamellæ, and toward the stem they are rounded on the lower angle and are not attached to the stem. The longer ones extend from near the stem to the margin of the pileus, and the V-shaped spaces between them are occupied by successively

Fig. 232.
Agaricus campestris. View of under side showing stem, annulus, gills, and margin of pileus.

Fig. 233.
Agaricus campestris. Longitudinal section through stem and pileus. *a*, pileus; *b*, portion of veil on margin of pileus; *c*, gill; *f*, fragment of annulus; *e*, stipe.

shorter ones. Around the stem a little below the gills is a collar, termed the ring or annulus.

421. Fruiting surface of the mushroom.—The surface of these gills is the fruiting surface of the mushroom, and bears the gonidia of the mushroom, which are dark purplish brown when mature, and thus the gills when old are dark in color. If we make a thin section across a few of the gills, we see that each side of the gill is covered with closely crowded club-shaped bodies, each one of which is a *basidium*. In fig. 234 a few of these are enlarged, so that the structure of the gill can be seen. Each basidium of the common mushroom has

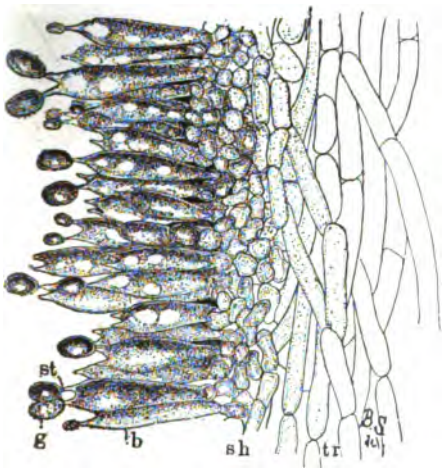

Fig. 234.

Portion of section of lamella of Agaricus campestris. *tr*, trama; *sh*, subhymenium; *b*, basidium; *st*, sterigma (*pl.* sterigmata); *g*, basidiospore.

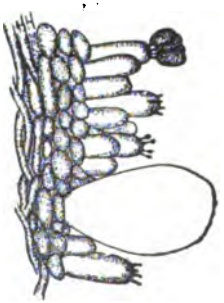

Fig. 235.

Portion of hymenium of Coprinus micaceus, showing large cystidium in the hymenium.

two spinous processes at the free end. Each one is a *sterig'ma* (plural *sterig'mata*), and bears a gonidium. In a majority of the members of the mushroom family each basidium bears four spores. When mature these spores easily fall away, and a mass of them gives a purplish-black color to objects on which they fall, so that a print of the under surface of the cap showing the arrangement of the gills can be obtained by cutting off the stem, and placing the pileus on white paper for a time.

422. How the mushroom is formed.—The mycelium of the

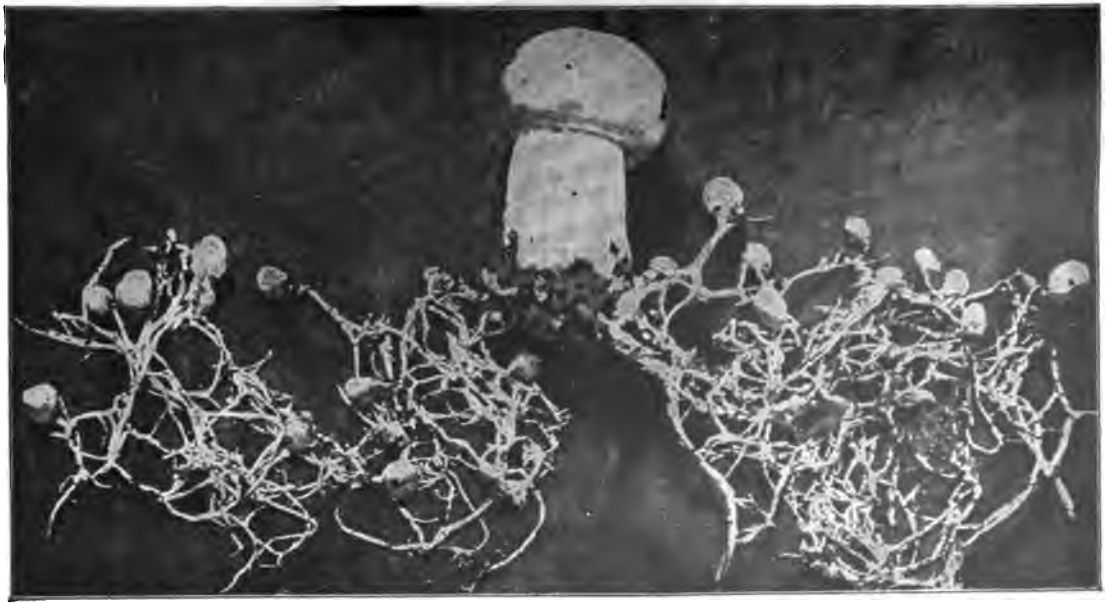

Fig. 230.

Agaricus campestris. Soil washed from "spawn" and "buttons," showing the minute young "buttons" attached to the strands of mycelium.

mushroom lives in the ground, and grows here for several months or even years, and at the proper seasons develops the mature mushroom plant. The mycelium lives on decaying organic matter, and a large number of the threads grow closely together forming strands, or cords, of mycelium, which are quite prominent if they are uncovered by removing the soil, as shown in fig. 236.

423. From these strands the buttons arise by numerous threads growing side by side in a vertical direction, each thread growing independently at the end, but all lying very closely side by

Fig. 237.
Agaricus campestris; sections of "buttons" of different sizes, showing formation of gills and veil covering them.

side. When the buttons are quite small the gills begin to form on the inside of the under margin of the knob. They are formed from an interior ring of tissue near the end of the young fruit body which appears before the end broadens into a knob. From this ring of tissue threads grow downward in radiating ridges, just as many ridges being started as there are to be gills formed. The lateral tissue outside of this interior ring of gills becomes the veil, and sections of young buttons will disclose the gills in the minute cavity thus formed (fig. 237). This curtain of mycelium which is thus stretched across the gill cavity is the veil. As the cap expands more and more this is stretched into a thin and delicate texture as

shown in fig. 238. Finally, as shown in fig. 239, this veil is ruptured by the expansion of the pileus, and it either clings

Fig. 238.

Agaricus campestris; nearly mature plants, showing veil still stretched across the gill cavity.

Fig. 240.

Agaricus campestris; plant in natural position just after rupture of veil, showing tendency to double annulus on the stem. Portions of the veil also dripping from margin of pileus.

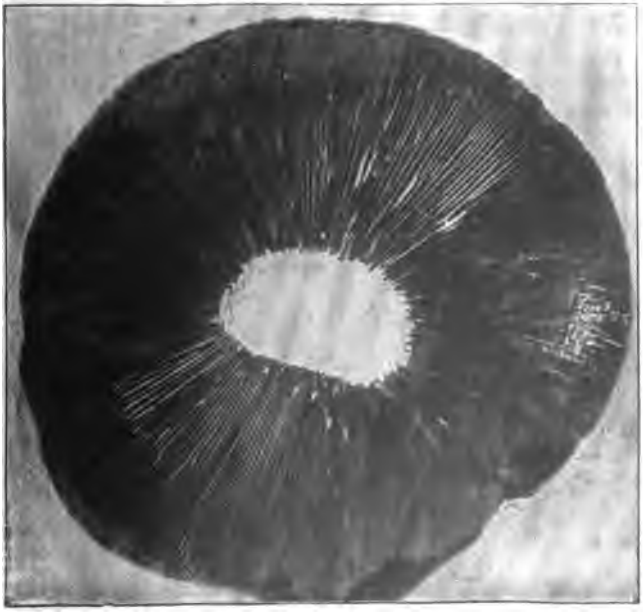

Fig. 241.
Agaricus campestris; spore print.

Fig. 242.

"Fairy ring" formed by Agaricus arvensis (photograph by B. M. Duggar). The mycelium spreads centrifugally each year, consuming the available food, and thus the plants appear in a ring.

to the stem as a collar, or a portion of it remains clinging to the margin of the cap. When the buttons are very young the gills are white, but they soon become pink in color, and

Fig. 243.
Amanita phalloides; white form, showing pileus, stipe, annulus, and volva.

very soon after the veil breaks the spores mature, and then the gills are dark brown.

424. Beware of the poisonous mushroom.—The number of species of mushrooms, or toadstools as they are often called, is very great. Besides the common mushroom (Agaricus campes-

tris) there are a large number of other edible species. But one should be very familiar with any species which is gathered for food, unless collected by one who certainly knows what the plant is, since carelessness in this respect sometimes results fatally from eating poisonous ones.

425. A plant very similar in structure to the Agaricus campestris is the Lepiota naucina, but the spores are white, and thus the gills are white, except that in age they become a dirty pink. This plant occurs in grassy fields and lawns often along with the

Fig. 244.

Amanita phalloides; plant turned to one side, after having been placed in a horizontal position, by the directive force of gravity.

common mushroom. Great care should be exercised in collecting and noting the characters of these plants, for a very deadly poisonous species, the deadly amanita (Amanita phalloides) is perfectly white, has white spores, a ring, and grows usually in wooded places, but also sometimes occurs in the margins of lawns. In this plant the base of the stem is seated in a cup-shaped structure, the *volva*, shown in fig. 243. One should dig up the stem carefully so as not to tear off this volva if it is present, for with the absence of this structure the plant might easily be mistaken for the lepiota, and serious consequences would result.

426. Tube-bearing fungi (Polyporaceæ).—In the tube-bearing fungi, the fruiting surface, instead of lying over the surface of gills, lines the surface of tubes or pores on the under side of the cap. The fruit-bearing portion therefore is "honey-combed." The sulphur polyporus (Polyporus sulphureus) illustrates one form. The tube-bearing fungi are sometimes called "bracket" fungi, or "shelf" fungi, because the pileus is attached to the

Fig. 245.
Edible Boletus. Boletus edulis. Fruiting surface honey-combed on under side of cap.

tree or stump like a shelf or bracket. One very common form in the woods is the plant so much sought by "artists," and often called Polyporus applanatus. It is hard and woody, reddish brown, brown or grayish on the upper side, according to age, and is marked by prominent and large concentric ridges. (This form is probably P. leucophæus.) The under side is white and honey-combed by numerous very minute pores. This plant is perennial, that is, it lives from year to year. Each year a new layer is added to the under side, and several new rings usually to the margin. If a plant two or three years old is cut in two, there will be seen several distinct tube layers or strata, each one representing a year's growth.

In some of these bracket fungi, each ring on the upper surface marks a

year's growth as in the pine polyporus (P. pinicola). In the birch polyporus (P. fomentarius) the tubes are quite large. It also occurs on other trees. The beech polyporus (P. igniarius, also on other trees) often be-

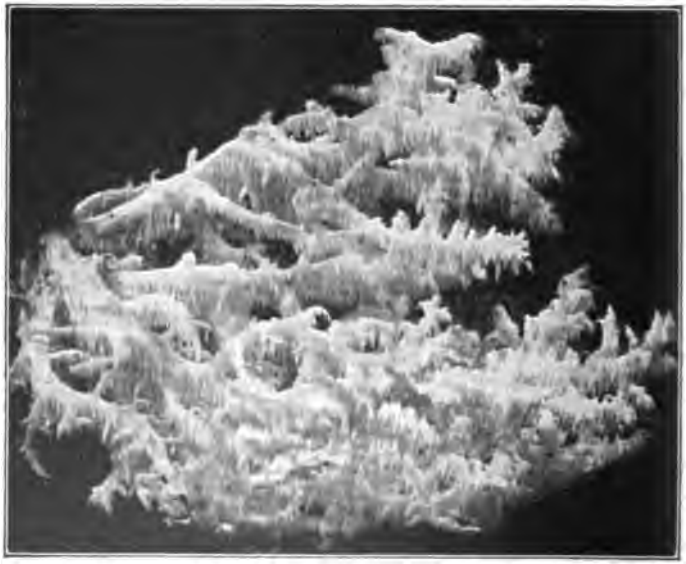

Fig. 246.
Coral fungus. Hydnum coralloides, spines hanging down from branches.

comes very old. I have seen one specimen over eighty years old. Not all the tube-bearing fungi are bracket form. Some have a stem and cap (see fig. 245). Some are spread on the surface of logs.

427. Hedgehog fungi (Hydnaceæ).—These plants are bracket in form or have a stem and cap, or are spread on the surface of wood; but the finest specimens resemble coral masses of fungus tissue (example, Hydnum, fig. 246). In most of them there are slender processes resembling teeth, spines or awls, which depend from the under surface (fig. 247). The fruiting surface covers these spines.

428. Coral fungi or fairy clubs (Clavariaceæ).—These plants stand upright from the wood, leaves, or soil, on which they grow (example, Clavaria). The "coral" ones are branched, while the "fairy clubs" are simple. The fruiting surface covers the entire exposed surface of the plants (fig. 248).

Fig. 247.
Hydnum repandum, spines hanging down from under side of cap.

Fig. 248.
Clavaria botrytes.

CHAPTER XXII.

CLASSIFICATION OF THE FUNGI.

429. Classification of the fungi.—Those who believe that the fungi represent a natural group of plants arrange them in three large series related to each other somewhat as follows:

The Gonidium Type or Series. The number of gonidia in the sporangium is indefinite and variable. It may be very large or very small, or even only one in a sporangium. To this series belong the lower fungi; examples: mucor, saprolegnia, peronospora, etc.

The Basidium Type or Series. The number of gonidia on a basidium is limited and definite, and the basidium is a characteristic structure; examples: uredineæ (rusts), mushrooms, etc.

The Ascus Type or Series. The number of spores in an ascus is limited and definite, and the ascus is a characteristic structure; examples: leaf curl of peach (exoascus), powdery mildews, black knot of plum, black rot of grapes, etc.

430. Others believe that the fungi do not represent a natural group, but that they have developed off from different groups of the algæ by becoming parasitic. As parasites they no longer needed chlorophyll, and consequently lost it.

According to this view the lower fungi have developed off from the lower algæ (saprolegnias, mucors, peronosporas, etc., being developed off from siphonaceous algæ like vaucheria), and the higher fungi being developed off from the higher algæ (the ascomycetes perhaps from the Rhodophyceæ).

431. A very general outline of classification,* according to the former of

* **Class Myxomycetes, or Mycetozoa.**—To this class belong the "slime molds," low organisms consisting of masses of naked protoplasm which flows among decaying leaves and in decaying wood, coming to the surface to fruit. The fruit in many cases resembles miniature puff-balls, and these plants were formerly classed with the puff-balls. The spores germinate by

these views, might be presented here to show the general relationships of the fungi studied, with the addition of a few more in orders not represented above. It should be borne in mind that the author in presenting this view of classification does not necessarily commit himself to it. It is based on that presented in Engler & Prantl's Pflanzenfamilien. There are three classes.

I. Class Phycomycetes (Alga-like Fungi).

1. SUBCLASS OOMYCETES.

432. These are the egg-spore fungi. They include the water mold (Saprolegnia), the downy mildew of the grape (Plasmopara), the potato

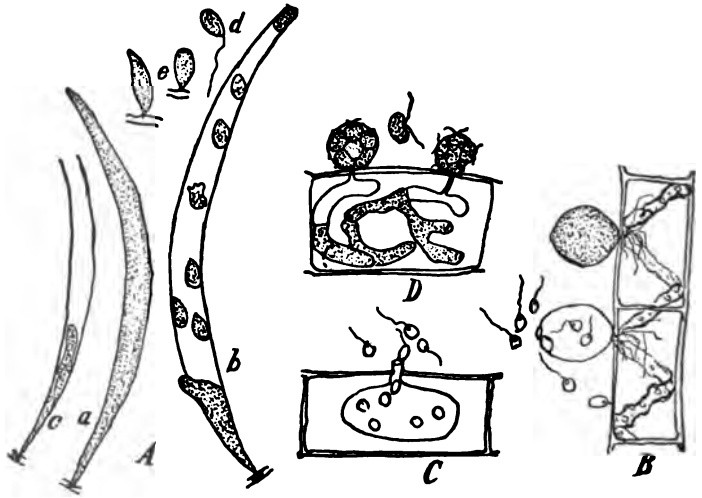

Fig. 249.

Chytrids. *A*, Harpochytrium hedenii, parasitic on spirogyra threads; *a*, sickle-form plant; *b*, the sporangium part with escaping zoospores; *c*, old plant proliferating by forming new sporangium in the old empty one; *d*, zoospore; *e*, two young plants just beginning to grow. *B*, Rhizophidium globosum parasitic on spirogyra. Globose sporangium with delicate threads inside of the host, zoospores escaping from one. *C*, Olpidium pendulum, parasitic in spirogyra cell. Elliptical sporangium with slender exit tube through which zoospores are escaping. *D*, Lagenidium rabenhorstii parasitic in spirogyra cell. Two slender sporangia with exit tubes through which protoplasm escapes forming a rounded mass at the end of tube, this protoplasm forming biciliate zoospores.

forming swarm spores which unite to form a small plasmodium, which in turn grows to form a large plasmodium or protoplasmic mass. It is doubtful if they are any more plant than animal organisms. Examples: Trichia, Arcyria, Stemonitis, Physarum, Ceratiomyxa, etc., on rotten wood; Plasmodiophora brassicæ is a parasite causing club foot of cabbage, radishes, etc. It lives within the roots, causing large knots and swellings on the same.

blight (Phytophthora), the white rust of cruciferous plants (Cystopus= Albugo), the damping-off fungus (Pythium), and many parasites of the algæ known as chytrids, as Olpidium, Rhizophidium, Lagenidium, Chytridium, etc.

The two following orders are sometimes placed in a separate subclass, *Archimycetes.*

433. Order Chytridiales (Chytridineæ).—These include the lowest fungi. Many of them are parasitic on algæ and lack mycelium, the swarm spore either with or without minute rhizoids, developing into a globose sporangium (Rhizophidium, Chytridium, Olpidium, etc., fig. 249), or the swarm spore attached to the wall of the host develops into a long sword-shaped body with a sterile base, which proliferates and forms a new sporangium in the old one (Harpochytrium), or with slight development of mycelium in aquatic plants (Cladochytrium). Some are parasitic in leaves and stems of land plants. Synchytrium decipiens is very common on the trailing legume, Amphicarpæa monoica.

434. Order Ancylistales (Ancylistineæ).—The members of this order have a slight development of mycelium and many are parasitic in algæ (Lagenidium, fig. 249).

435. Order Saprolegniales (Saprolegniineæ).—These include the water molds (Saprolegnia). See Chapter XIX.

436. Order Monoblepharidales (Monoblepharidineæ).—These are peculiar water molds, related to the Saprolegniales, but motile sperm cells are formed (Monoblepharis, etc., fig. 250).

Fig. 250.

Monoblepharis insignis Thaxter. End of hypha bearing oogonium (*oog*) and antheridium (*ant*). Sperms escaping from antheridium and creeping up on the oogonium. (After Thaxter.)

437. Order Peronosporales (Peronosporineæ).—These include the downy mildews (Peronospora, Plasmopara, Phytopthora, etc.), and the white rust of crucifers and other plants (Cystopus= Albugo), Chapter XIX.

2. SUBCLASS ZYGOMYCETES.

438. These are the conjugating fungi.

439. Order Mucorales (Mucorineæ).—This includes the black mold and its many relatives (Mucor, Rhizopus, etc.). Chapter XIX.

440. Order Entomophthorales (Entomophthorineæ).—This order includes the "fly fungus" (Empusa) and its many relatives parasitic on insects.

In the autumn and winter dead flies are often found stuck to window-panes, with a white ring of the conidia around each fly.

II. Class Ascomycetes. (The ascus series.)

1. SUBCLASS HEMIASCOMYCETES.

441. Order Hemiascales (Hemiascineæ).—Fungi with a well developed, septate mycelium, but with a sporangium-like ascus, i.e., a large and indefinite number of spores in the ascus. Examples: Protomyces macrosporus in stems of Umbelliferæ, or P. polysporus in Ambrosia trifida. These two are by some placed in the Ustilagineæ. Dipodascus albidus grows in the exuding sap of Bromeliaceæ in Brazil and the sap of the beech in Sweden. The ascus is developed as the result of the fertilization of an ascogonium with an antheridium (see fig. 251).

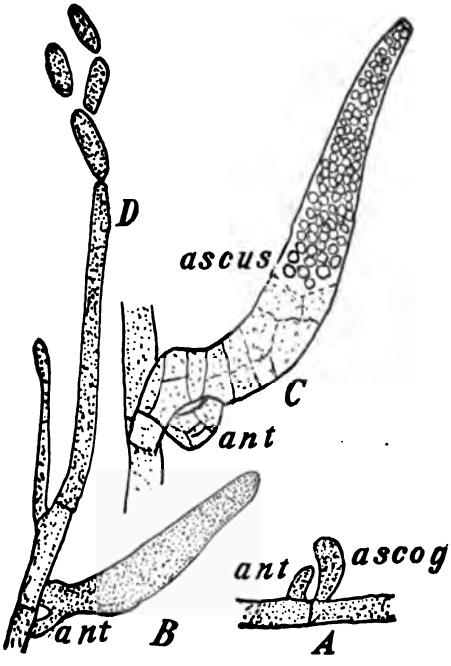

Fig. 251.

Dipodascus albidus. *A*, thread with sexual organs, ascogonium and antheridium; *B*, fertilized ascogonium developing ascus; *C*, ascus with spores; *D*, conidia. (After Lagerheim.)

2. SUBCLASS PROTOASCOMYCETES.

442. The asci are well defined and usually with a limited and definite number of spores (usually 8, sometimes 1, 2, 4, 16, or more). Mycelium often well developed and septate. Asci scattered on the mycelium, not associated in definite fields or groups.

443. Order Protoascales (Protoascineæ).—The asci are separate cells, or are scattered irregularly in loose wefts of mycelium. No fruit body. (The yeast, Saccharomyces, see paragraph 237; and certain mold-like fungi, some of which are parasitic on mushrooms, as Endomyces, are examples.)

3. SUBCLASS EUASCOMYCETES.

Asci associated in surfaces forming a hymenium, or in groups or intermingled in the elements of a fruit body. Fruit body usually present.

The following four or five orders comprise the Discomycetes, according to the usual classification.

444. Order Protodiscales (Protodiscineæ).—The asci are exposed and form large and indefinite groups, but there is no definite fruit body. Examples: leaf curl of peach, plum pocket, etc. (Exoascus).

445. Order Helvellales (Helvellineæ).—The asci form large fields over the upper portion of the fruit body. This order includes the morels (fig. 231*a*), helvellas, earth tongues (Geoglossum), etc.

446. Order Pezizales (Pezizineæ).—The asci form a definite field or fruiting surface surrounded on the sides and below by a wall of fungus tissue, forming a fruit body in the shape of a cup. These are known as the cup fungi (Peziza, Lachnea, etc.).

447. Order Phacidiales (Phacidiineæ).—Fungi mostly saprophytic, and fruit body similar to the cup fungi. Examples: Propolis in rotting wood, Rhytisma forming black crusts on leaves (maple for example), Urnula craterium, a large black beaker-shaped fungus on the ground.

448. Order Hysteriales (Hysteriineæ).—Fungi with a more or less elongated fruit body with an enclosing wall opening by a long slit. In some forms the fruit body has the appearance of a two-lipped body; in others it is shaped like a clam shell, the asci being inside. Example, Hysterographium common on dry, dead, decorticated sticks.

449. Order Tuberales (Tuberineæ).—The more or less rounded fruit bodies are usually subterranean. The most important fungi in this order are the truffles (Tuber). The mycelium of many species assists in the formation of mycorhiza on the roots of oaks, etc., and several species are partly cultivated, or protected, and collected for food. This is especially the case with Tuber brumale and its forms; more than a million francs worth of truffles are sold in France and Italy yearly. Dogs and pigs are employed in the collection of truffles from the ground.

450. Order Plectascales (Plectascineæ).—The fruit body of these plants is more or less globose, and contains the asci distributed irregularly through the mycelium of the interior. Some are subterranean (Elaphomyces), while others grow in decaying plants, or certain food substances (Eurotium, Sterigmatocystis, Penicillium). Penicillium in its conidial stage forms blue mold on fruit, bread, etc.

The following four orders comprise the Pyrenomycetes, according to the usual classification.

451. Order Perisporiales.—The powdery mildews are good examples of this order (Uncinula, Microsphæra, etc., Chapter XXI).

452. Order Hypocreales.*—The fruit bodies are colorless, or bright colored and entirely enclose the asci, sometimes opening by an apical pore. Nectria cinnabarina has clusters of minute orange oval fruit bodies, and is common on dead twigs. Cordyceps with a number of species is parasitic on insects, and on certain subterranean Ascomycetes, especially Elaphomyces (of the order *Plectascales*= *Plectascineæ*).

453. Order Dothidiales.*—Fungi with black stroma formed of mycelium in which are cavities containing the asci. The cavities are usually shaped like a perithecium, but there is no wall distinct from the tissue of the stroma (Dothidea, Phyllachora, on grasses).

454. Order Sphæriales.*—These contain the so-called black fungi, with separate or clustered, oval, fruit bodies, black in color. The black wall encloses the asci, and usually opens by an apical pore. Examples are found in the black knot of plum and cherry, black rot of grapes, and in Rosellinia, Hypoxylon, Xylaria, etc., on dead wood.

455. Order Laboulbeniales (Laboulbineæ).—These are peculiar fungi attached to the legs and bodies of insects by a short stalk, and provided with a sac-like fruit body which contains the asci. Example, Laboulbenia.

III. Class Basidiomycetes. (The basidium series.)

1. SUBCLASS HEMIBASIDIOMYCETES.

456. Order Ustilaginales (Ustilagineæ).—This order includes the well-known smuts on corn, wheat, oats, etc. (Ustilago, Tilletia, etc.).

2. SUBCLASS ÆCIDIOMYCETES.

457. Order Uredinales† (Uredineæ).—This order includes the parasitic fungi known as rusts. Examples: wheat rust (Chapter XX), the cedar apple, etc.

The true Basidiomycetes include the following orders:

3. SUBCLASS PROTOBASIDIOMYCETES.

458. Order Auriculariales.†—This order includes trembling fungi in which the basidium is long and divided transversely into usually four cells (example, Auricularia), and similar forms. Pilacre petersii on dead wood represents an angiocarpous form.

459. Order Tremellales (**Tremellineæ**), trembling or gelatinous fungi with the globose basidium divided longitudinally into four cells (Tremella).

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* As suborder in Engler and Prantl.

† The Uredinales and Auriculariales in Engler and Prantl are placed in one order, Auriculariineæ.

4. SUBCLASS EUBASIDIOMYCETES.

460. Order Dacryomycetales (Dacryomycetineæ).—This order includes certain fungi of a gelatinous or waxy consistency, usually of bright colors. They resemble the Tremellales, but the basidia are slender and fork into two long sterigmata. (Example, Dacryomyces.) Gyrocephalus rufus is quite a large plant, 10–15 cm. high, growing on the ground in woods.

461. Order Exobasidiales (Exobasidiineæ).—The fungus causing azalea apples is an example (Exobasidium).

462. Order Hymeniales (Hymenomycetineæ).—In this order the basidia are usually club-shaped and undivided, and bear usually four spores on the end (sometimes two or six). There are several families.

463. Family Thelephoraceæ.—The fruit bodies are more or less membranous and spread over wood or the ground, or somewhat leaflike, growing on wood or the ground. The fruiting surface is nearly or quite even, and occupies the under side of the leaflike bodies (Stereum, Thelephora) or the outside of the forms spread out on wood (Corticium, Coniophora).

464. Family Clavariaceæ.—This order includes the fairy clubs, and some of the coral fungi. The larger number of species are in one genus (Clavaria, fig. 248).

465. Family Hydnaceæ.—The fungi of this order are known as "hedgehog" fungi, because of the numerous awl-like teeth or spines over which the fruiting surface is spread, as in Hydnum (figs. 246, 247).

466. Family Polyporaceæ.—The tube-bearing fungi (Polyporus, Boletus, etc., fig. 245).

467. Family Agaricaceæ.—The gill-bearing fungi (Agaricus, Amanita, etc., see Chapter XXI).

The above five orders, according to the earlier classification (still used at the present time by some), made up the order Hymenomycetes, while the following five orders made up the Gasteromycetes. The Hymenomycetes, according to this system, included those plants in which the fruiting portion (hymenium) is either exposed from the first, or if covered by a veil or volva (as in Agaricus, Amanita, etc.) this ruptures and exposes the fruiting surface before, or at the time of, the ripening of the spores, while the Gasteromycetes included those in which the fruit body is closed until after the maturity of the spores.

468. Order Phallales (Phallineæ).—The "stink-horn" fungi, or "buzzard's nose." Usually foul-smelling fungi, the fruiting portion borne aloft on a stout stalk, and dissolving (Dictyophora, Ithyphallus, etc.).

469. Order Hymenogastrales (Hymenogastrineæ).—The basidia form a distinct hymenium on walls of chambers, which do or do not break down at maturity, but there are no sterile threads forming a capillitium. Some of the plants resemble Boletus or Agaricus in the way the fruit bodies open (Secotium, etc.), while others open irregularly on the surface (Rhizopogon) or

like an earth star (Sclerogaster), or portions of the surface become gelatinized (Phallogaster). The last-named one grows on very rotten wood, while most of the others grow on the ground.

470. Order Lycoperdales (Lycoperdineæ). — These include the "puff-balls," or "devil's snuff-box" (Lycoperdon), and the earth stars (Geaster). The basidia form a distinct hymenium, but at maturity the entire inner portion of the plant (except certain peculiar threads, the capillitium) disintegrates and with the spores forms a powdery mass.

471. Order Nidulariales (Nidulariineæ).—These are known as bird-nest fungi. The fruit body when mature is cup-shaped, or goblet-shaped, and contains minute flattened circular bodies (peridiola) containing the spores. The intermediate portions of the fruit body disintegrate and set the peridiola free, which then lie in the cup-shaped base like eggs in a nest.

472. Order Plectobasidiales (Plectobasidiineæ).—The basidia do not form a definite hymenium, but are interwoven with the threads inside, or are collected into knot-like groups. (Examples: Calostoma, Tulostoma, Astræus, Sphærobolus, etc.)

472a. Lichens.—The plant body of the lichens (see paragraphs 200, 201) consists of two component parts, the one a fungus, the other an alga. The fructification is that of the fungus. The fruit body shows the lichens to be related some to the Ascomycetes, others to the Hymenomycetes, and Gasteromycetes. They are usually classified as a distinct class or order from the fungi, but a natural arrangement would distribute them in several of the orders above. Their special relationship with these orders has not been satisfactorily worked out. For the present they are arranged as follows:

Ascolichenes.

Pyrenocarpous lichens (those with a fruit body like the Pyrenomycetes).

Gymnocarpous lichens (those with a fruit body like the Discomycetes).

Hymenolichenes (those with a fruit body like the Hymenomycetes).

Gasterolichenes (those with a fruit body like the Gasteromycetes).

From a vegetative standpoint there are two types according to the distribution of the elements.

1st. Where the fungal and algal elements are evenly distributed in the plant body the lichen is said to be *homoiomerous*. There are two types of these:

a. Filamentous lichens, example, Ephebe pubescens.

b. Gelatinous lichens, example, Collema (with the alga nostoc), Physma (with the Chroococcaceæ).

2d. Where the elements are stratified, as in Parmelia, etc., the lichen is said to be *heteromerous*. In these there are three types:

a. Crustaceous lichens, the plant body is in the form of a thin incrustation on rocks, etc.

b. Foliaceous lichens, the plant body is leaflike and lobed and more or less loosely attached by rhizoids: Parmelia, Peltigera, etc.

Fig. 251*a*.
Rock lichen (Parmelia contigua).

c. Fruticose lichens, the plant body is filamentous or band-like and branched, as in Usnea, Cladonia, etc.

CHAPTER XXIII.

LIVERWORTS (HEPATICÆ).

473. We come now to the study of representatives of another group of plants, a few of which we examined in studying the organs of assimilation and nutrition. I refer to what are called the liverworts. Two of these liverworts belonging to the genus riccia are illustrated in figs. 30, 252.

Riccia.

474. Form of the floating riccia (R. fluitans).—The general form of floating riccia is that of a narrow, irregular, flattened, ribbon-like object, which forks repeatedly, in a dichotomous manner, so that there are several lobes to a single plant. It receives its name from the fact that at certain seasons of the year it may be found floating on the water of pools or lakes. When the water lowers it comes to rest on the damp soil, and rhizoids are developed from the under side. Now the sexual organs, and later the fruit capsule, are developed.

475. Form of the circular riccia (R. crystallina).—The circular riccia is shown in fig. 252. The form of this one is quite different from the floating one, but the manner of growth is much the same. The branching is more compact and even, so that a circular plant is the result. This riccia inhabits muddy banks, lying flat on the wet surface, and deriving its soluble food by means of the little rootlets (rhizoids) which grow out from the under surface.

Here and there on the margin are narrow slits, which extend

nearly to the central point. They are not real slits, however, for they were formed there as the plant grew. Each one of these V-shaped portions of the thallus is a lobe, and they were formed in the young condition of the plant by a branching in a forked manner. Since growth took place in all directions radially the plant became circular in form. These large lobes we can see are forked once or twice again, as shown by the seeming shorter slits in the margin.

Fig. 252.
Thallus of Riccia crystallina.

476. Sexual organs. — In order to study the sexual organs we must make thin sections through one of these lobes lengthwise and perpendicular to the thallus surface. These sections are mounted for examination with the microscope.

477. Archegonia.—We are apt to find the organs in various stages of development, but we will select one of the flask-shaped structures shown in fig. 253 for study. This flask-shaped body we see is entirely sunk in the tissue of the thallus. This structure is the female organ, and is what we term in these plants the *archegonium.* It is more complicated in structure than the oogonium. The lower portion is enlarged and bellied out, and is the venter of the archegonium, while the narrow portion is the neck. We here see it in section. The wall is one cell layer in thickness. In the neck is a canal, and in the base of the venter we see a large rounded cell with a distinct and large nucleus. This cell is the *egg* cell.

478. Antheridia.—The antheridia are also borne in cavities sunk in the tissue of the thallus. There is here no illustration of the antheridium of this riccia, but fig. 259 represents an antheridium of another liverwort, and there is not a great difference between the two kinds. Each one of those little rectangular sperm mother cells in the antheridium changes into a swiftly moving body like a little club with two long lashes attached to the smaller end By the violent lashing of these organs the spermatozoid is moved through the water, or moisture which is on the surface of the thallus. It moves through the canal of the archegonium neck and into the egg, where it fuses with the nucleus of the egg, and thus fertilization is effected.

479. Embryo.—In the plants which we have selected thus far for study, the egg, immediately after fecundation, we recollect, passed into a resting state, and was enclosed by a thick protecting wall. But in riccia, and in the other plants of the group which we are now studying, this is not the case.

Fig. 253.

Archegonium of riccia, showing neck, venter, and the egg; archegonium is partly surrounded by the tissue of the thallus. (Riccia crystallina.)

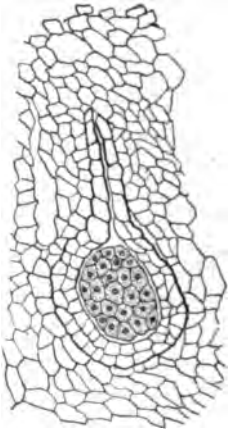

Fig. 254.

Young embryo (sporogonium) of riccia, within the venter of the archegonium; the latter has now two layers of cells. (Riccia crystallina.)

The egg, on the other hand, after acquiring a thin wall, swells up and fills the cavity of the venter. Then it divides by a cross wall into two cells. These two grow, and divide again, and so on until there is formed a quite large mass of cells rounded in form and still contained in the venter of the archegonium, which itself increases in size by the growth of the cells of the wall.

480. Sporogonium of riccia.—The fruit of riccia, which is developed from the fertilized egg in the archegonium, forms a rounded capsule still enclosed in the venter of the archegonium, which grows also to provide space for it. Therefore a section through the plant at this time, as described for the study of the archegonium, should show this capsule. The capsule then is a rounded mass of cells developed from the egg. A single outer layer of cells forms the wall, and therefore is sterile.

All the inner cells, which are richer in protoplasm, divide into four cells each. Each of these cells becomes a spore with a thick wall, and is shaped like a triangular pyramid whose sides are of the same extent as the base (tetrahedral). These cells formed in

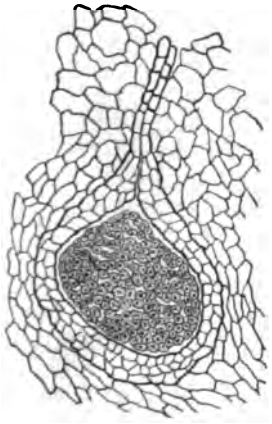

Fig. 255.

Nearly mature sporogonium of Riccia crystallina; mature spore at the right.

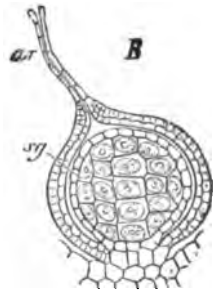

Fig. 256.

Riccia glauca; archegonium containing nearly mature sporogonium. *sf*, spore-producing cells surrounded by single layer of sterile cells, the wall of the sporogonium.

fours are the *spores*. At this time the wall of the spore-case dissolves, the spores separate from each other and fill the now enlarged venter of the archegonium. When the thallus dies they are liberated, or escape between the loosely arranged cells of the upper surface.

481. A new phase in plant life.—Thus we have here in the sporogonium of *riccia* a very interesting phase of plant life, in which the egg, after fertilization, instead of developing directly into the same phase of the plant on which it was formed, grows into a quite new phase, the sole function of which is the development of spores. Since the form of the plant on which the sexual organs are developed is called the *gametophyte*, this new phase in which the spores are developed is termed the *sporophyte*.

Now the spores, when they germinate, develop the *gametophyte*, or thallus, again. So we have this very interesting condi-

tion of things, the thallus (gametophyte) bears the sexual organs and the unfertilized egg. The fertilized egg, starting as it does from a single-celled stage, develops the sporogonium (sporophyte). Here the single-cell stage is again reached in the spore, which now develops the thallus.

482. Riccia compared with coleochæte, œdogonium, etc.—We have said that in the sporogonium of riccia we have formed a new phase in plant life. If we recur to our study of coleochæte we may see that there is here possibly a state of things which presages, as we say, this new phase which is so well formed in riccia. We recollect that after the fertilized egg passed the period of rest it formed a small rounded mass of cells, each of which now forms a zoospore. The zoospore in turn develops the normal thallus (gametophyte) of the coleochæte again. In coleochæte then we have two phases of the plant, each having its origin in a one-celled stage. Then if we go back to œdogonium, we remember that the fertilized egg, before it developed into the œdogonium plant again (which is the gametophyte), at first divides into *four* cells which become zoospores. These then develop the œdogonium plant.

Note. Too much importance should not be attached to this seeming homology of the sporophyte of œdogonium, coleochæte, and riccia, for the nuclear phenomena in the formation of the zoospores of œdogonium and coleochæte are not known. They form, however, a very suggestive series.

Marchantia.

483. The marchantia (M. polymorpha) has been chosen for study because it is such a common and easily obtained plant, and also for the reason that with comparative ease all stages of development can be obtained. It illustrates also very well certain features of the structure of the liverworts.

The plants are of two kinds, male and female. The two different organs, then, are developed on different plants. In appearance, however, before the beginning of the structures which bear the sexual organs they are practically the same. The thallus is flattened like nearly all of the thalloid forms, and branches in a forked manner. The color is dark green, and through the middle line of the thallus the texture is different from that of the margins, so that it possesses what we term a

midrib, as shown in figs. 257, 261. The growing point of the thallus is situated in the little depression at the free end. If we examine the upper surface with a hand lens we see diamond-shaped areas, and at the center of each of these areas are the openings known as the stomates.

484. Antheridial plants.—One of the male plants is figured at 257. It bears curious structures, each held aloft by a short stalk. These are the antheridial receptacles (or male gametophores). Each one is circular, thick, and shaped somewhat like a biconvex lens. The upper surface is marked by radiating furrows, and the margin is crenate. Then we note, on careful examination of the upper surface, that there are numerous minute openings. If we make a thin section of this structure perpendicular to its surface we shall be able to unravel the mystery of its interior. Here we see, as shown in fig. 258, that each one of these little openings on the surface is an entrance to quite

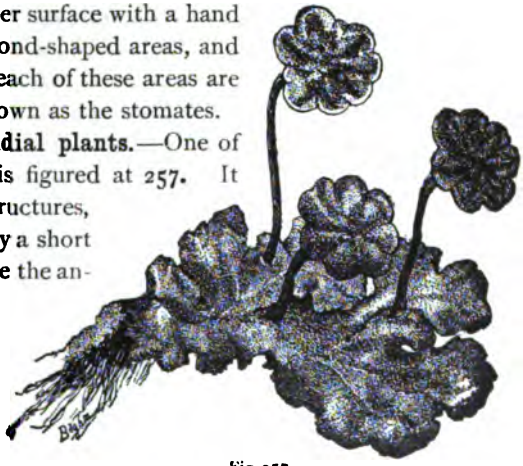

Fig. 257.
Male plant of marchantia bearing antheridiophores.

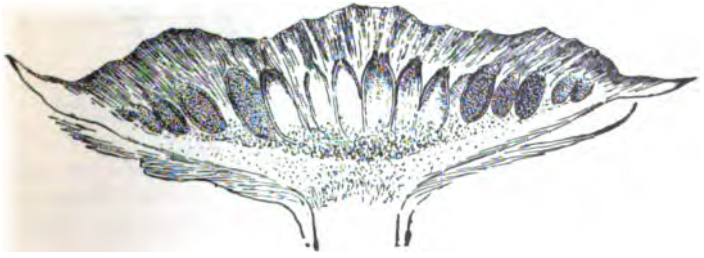

Fig. 258.
Section of antheridial receptacle from male plant of Marchantia polymorpha, showing cavities where the antheridia are borne.

a large cavity. Within each cavity there is an oval or elliptical body, supported from the base of the cavity on a short stalk. This is an antheridium, and one of them is shown still more enlarged in fig. 259. This shows the structure of the antheridium, and that there are within several angular areas, which are divided by numerous straight cross-lines into countless tiny cuboidal cells, the *sperm mother cells*. Each of these, as stated in the former chapter, changes into a swiftly moving body resembling a serpent with two long lashes attached to its tail.

485. The way in which one of these sperm mother cells changes into this spermatozoid is very curious. We first note that a coiled spiral body is appear-

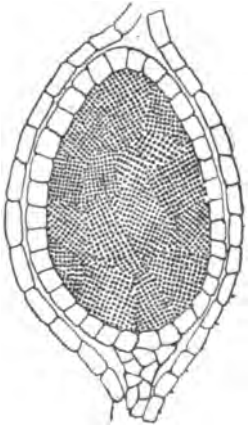

Fig. 259.
Section of antheridium of marchantia, showing the groups of sperm mother cells.

Fig. 260.
Spermatozoids of marchantia, uncoiling and one extended, showing the two cilia.

ing within the thin wall of the cell, one end of the coil larger than the other. The other end terminates in a slender hair-like outgrowth with a delicate vesicle attached to its free end. This vesicle becomes more and more extended until it finally breaks and forms two long lashes which are clubbed at their free ends as shown in fig. 260.

486. Archegonial plants.—In fig. 261 we see one of the female plants of marchantia. Upon this there are also very curious structures, which remind one of miniature umbrellas. The general plan of the archegonial receptacle (or female

gametophore), for this is what these structures are, is similar to that of the antheridial receptacle, but the rays are more pronounced, and the details of structure are quite different, as we shall see. Underneath the arms there hang down delicate fringed curtains. If we make sections of this in the same direc-

Fig. 261.
Marchantia polymorpha, female plants bearing archegoniophores.

tion as we did of the antheridial receptacle, we shall be able to find what is secreted behind these curtains. Such a section is figured at **266**. Here we find the archegonia, but instead of being sunk in cavities their bases are attached to the under

surface, while the delicate, pendulous fringes afford them protection from drying. An archegonium we see is not essentially different in marchantia from what it is in riccia, and it will be interesting to learn whether the sporogonium is essentially different from what we find in riccia.

487. Homology of the gametophore of marchantia.—To see the relation of the gametophore to the thallus of marchantia take portions of the thallus bearing the female receptacle. On the under side note that the prominent midrib continues beyond the thin lateral expansions and arches upward in the sinus or notch at the end, or at the side where the branch of the thallus has continued to grow beyond. The stalk of the gametophore is then a continuation of the midrib of the thallus. On the apex of this are organized several radial growing points which develop the digitate or ray-like receptacle. The gametophore is thus a specialized branch of the thallus. When young, or in many cases when nearly or quite mature, the gametophore, as one looks at the upper surface of the thallus, appears to arise from the upper surface, as in fig. 261. This is because the thin lateral expansions of the thallus project forward and overlap in advance of the stalk. It is sometimes necessary to tear these overlapping edges apart to see the real origin of the gametophore. But in quite old plants these expanded portions are farther apart and show clearly that the stalk arises from the midrib below and arches upward in the sinus, as in fig. 262.

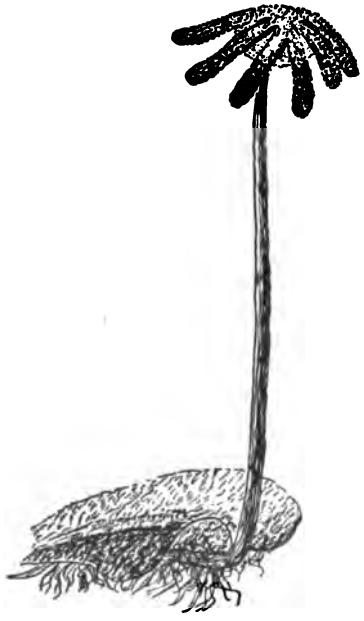

Fig. 262.

Marchantia polymorpha, showing origin of gametophore.

CHAPTER XXIV.

LIVERWORTS CONTINUED.

488. Sporogonium of marchantia.—If we examine the plant shown in fig. 181 we shall see oval bodies which stand out be-

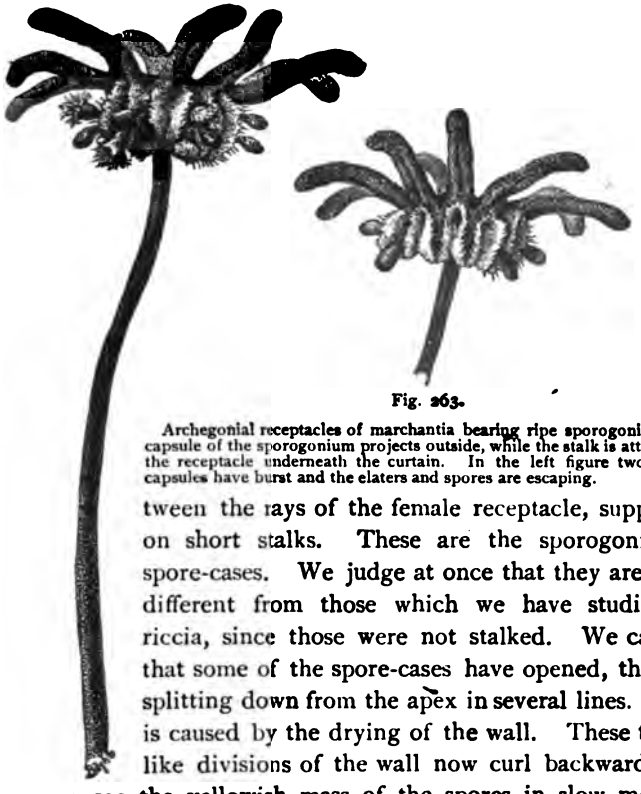

Fig. 263.

Archegonial receptacles of marchantia bearing ripe sporogonia. The capsule of the sporogonium projects outside, while the stalk is attached to the receptacle underneath the curtain. In the left figure two of the capsules have burst and the elaters and spores are escaping.

tween the rays of the female receptacle, supported on short stalks. These are the sporogonia, or spore-cases. We judge at once that they are quite different from those which we have studied in riccia, since those were not stalked. We can see that some of the spore-cases have opened, the wall splitting down from the apex in several lines. This is caused by the drying of the wall. These tooth-like divisions of the wall now curl backward, and we can see the yellowish mass of the spores in slow motion,

falling here and there. It appears also as if there were twisting threads which aided the spores in becoming freed from the capsule.

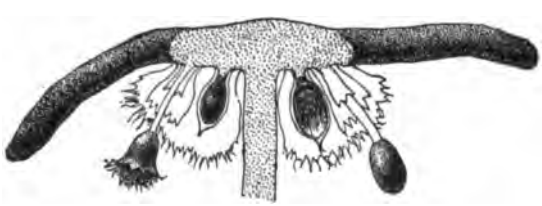

Fig. 264.

Section of archegonial receptacle of Marchantia polymorpha; ripe sporogonia. One is open, scattering spores and elaters; two are still enclosed in the wall of the archegonium. The junction of the stalk of the sporogonium with the receptacle is the point of attachment of the sporophyte of marchantia with the gametophyte.

489. Spores and elaters.—If we take a bit of this mass of spores and mount it in water for examination with the microscope, we shall see that, besides the spores, there are very peculiar thread-like bodies, the markings of which remind one of a twisted rope. These are very long cells from the inner part of the spore-case, and their walls are marked by spiral thickenings. This causes them in drying, and also when they absorb moisture, to twist and curl in all sorts of ways. They thus aid in pushing the spores out of the capsule as it is drying.

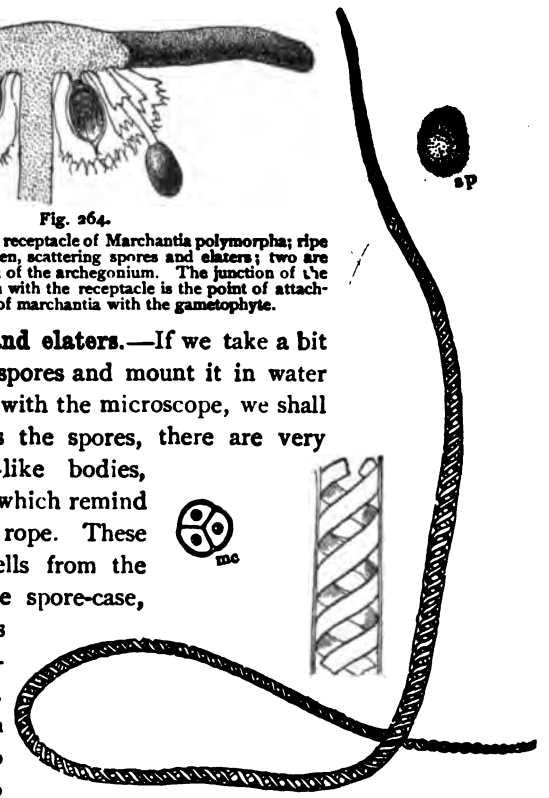

Fig. 265.

Elater and spore of marchantia. *sp*, spore; *mc*, mother-cell of spores, showing partly formed spores.

490. Sporophyte of marchantia compared with riccia.—We must recollect that the sporogonium in marchantia is larger than in riccia, and that it is also not lying in the tissue of the thallus, but is only attached to it at one side by a slender stalk.

This shows us an increase in the size and complex structure of this new phase of the plant, the *sporophyte*. This is one of the very interesting things which we have to note as we go on in the study of the higher plants.

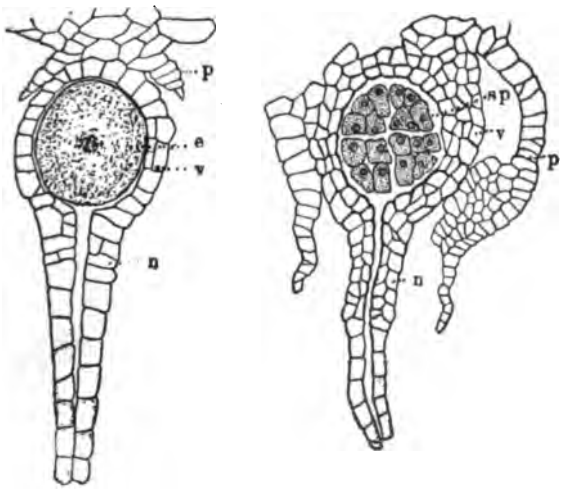

Fig. 266.

Marchantia polymorpha, archegonium at the left with egg; archegonium at the right with young sporogonium; *p*, curtain which hangs down around the archegonia; *e*, egg; *v*, venter of archegonium; *n*, neck of archegonium; *sp*, young sporogonium.

491. Sporophyte dependent on the gametophyte for its nutriment.—We thus see that at no time during the development of the sporogonium is it independent from the gametophyte. This new phase of plants then, the sporophyte, has not yet become an independent plant, but must rely on the earlier phase for sustenance.

492. Development of the sporogonium.—It will be interesting to note briefly how the development of the marchantia sporogonium differs from that of riccia. The first division of the fertilized egg is the same as in riccia, that is a wall which runs crosswise of the axis of the archegonium divides it into two cells. In marchantia the cell at the base develops the stalk, so that here there is a radical difference. The outer cell forms the capsule. But here after the wall is formed the inner tissue does not all go to make spores, as is the case with riccia. But some of it forms the elaters. While in riccia only the outside layer of cells of the sporogonium remained sterile, in marchantia the basal half of the egg remains completely sterile and

develops the stalk, and in the outer half the part which is formed from some of the inner tissue is also sterile.

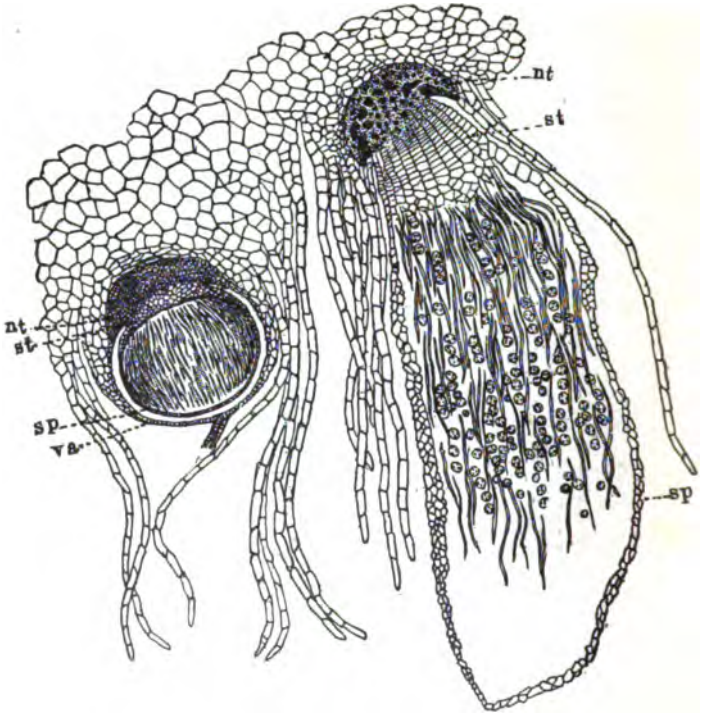

Fig. 267.

Section of developing sporogonia of marchantia; *nt*, nutritive tissue of gametophyte; *st*, sterile tissue of sporophyte; *sp*, fertile part of sporophyte; *va*, enlarged venter of archegonium.

493. Embryo.—In the development of the embryo we can see all the way through this division line between the basal half, which is completely sterile, and the outer half, which is the fertile part. In fig. 267 we see a young embryo, and it is nearly circular in section although it is composed of numerous cells. The basal half is attached to the base of the inner surface of the archegonium, and at this time the archegonium still surrounds it. The archegonium continues to grow then as the embryo grows, and we can see the remains of the shrivelled neck. The portion of the embryo attached to the base of the archegonium is the sterile part and is called the "foot," and later develops the stalk. The sporogonium during all the stages of its development derives its nourishment from the gametophyte at this point of

attachment at the base of the archegonium. Soon, as shown in fig. 267 at the right, the outer portion of the sporogonium begins to differentiate into the cells which form the elaters and those which form spores. These lie in radiating lines side by side, and form what is termed the *archesporium.* Each fertile cell forms four spores just as in riccia. They are thus called the mother cells of the spores, or spore mother cells.

494. How marchantia multiplies.—New plants of marchantia are formed by the germination of the spores, and growth of the same to the thallus. The plants may also be multiplied by parts of the old ones breaking away by the action of strong currents of water, and when they lodge in suitable places grow into well-formed plants. As the thallus lives from year to year and continues to grow and branch the older portions die off, and thus separate plants may be formed from a former single one.

495. Buds, or gemmæ, of marchantia.—But there is another way in which marchantia multiplies itself. If we examine the upper surface of such a

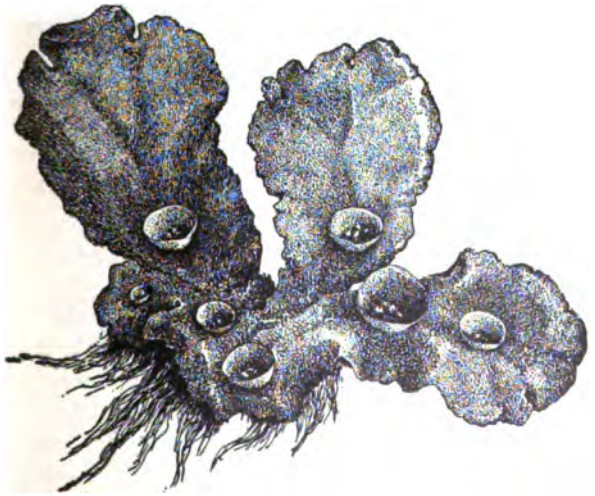

Fig. 268.

Marchantia plant with cupules and gemmæ; rhizoids below.

plant as that shown in fig. 268. we shall see that there are minute cup-shaped or saucer-shaped vessels, and within them minute green bodies. If we examine a few of these minute bodies with the microscope we see that they are flattened, biconvex, and at two opposite points on the margin there is an indentation similar to that which appears at the growing end of the old marchantia thallus. These are the growing points of these little buds. When they free themselves from the cups they come to lie on one

side. It does not matter on what side they lie, for whichever side it is, that will develop into the lower side of the thallus, and forms rhizoids, while the upper surface will develop the stomates.

Leafy-stemmed liverworts.

496. We should now examine more carefully than we have done formerly a few of the leafy-stemmed liverworts (called foliose liverworts).

497. Frullania (Fig. 32).—This plant grows on the bark of logs, as well as on the bark of standing trees. It lives in quite dry situations. If we examine the leaves we will see how it is able to do this. We note that there are two rows of lateral leaves, which are very close together, so close in fact that they overlap like the shingles on a roof. Then, as the creeping stems lie very close to the bark of the tree, these overlapping leaves, which also hug close to the stem and bark, serve to retain moisture which trickles down the bark during rains. If we examine these leaves from the under side as shown in fig. 34, we see that the lower or basal part of each one is produced into a peculiar lobe which is more or less cup-shaped. This catches water and holds it during dry weather, and it also holds moisture which the plant absorbs during the night and in damp days.

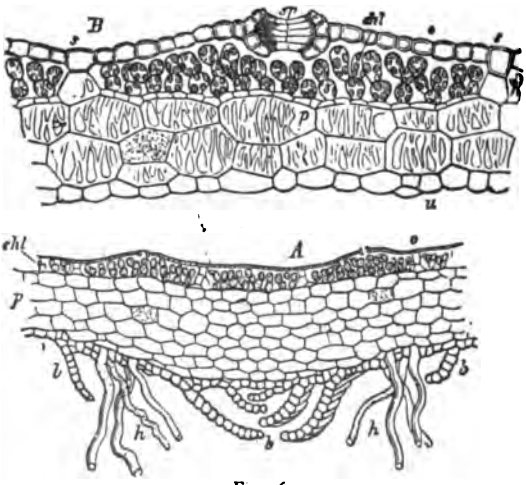

Fig. 269.

Section of thallus of marchantia. *A*, through the middle portion; *B*, through the marginal portion; *p*, colorless layer; *chl*, chlorophyll layer; *sp*, stomate; *h*, rhizoids; *b*, leaf-like outgrowths on under side (Goebel).

There is so much moisture in these little pockets of the under side of the leaf that minute animals have found them good places to live in, and one frequently discovers them in this retreat. There is here also a third row of poorly developed leaves on the under side of the stem.

498. Porella.—Growing in similar situations is the plant known as porella. Sometimes there are a few plants in a group, and at other times large mats occur on the bark of a trunk. This plant, porella, also has closely overlapping leaves in rows on opposite sides of the stem, and the lower margin of each leaf is curved under somewhat as in frullania, though the pocket is not so well formed.

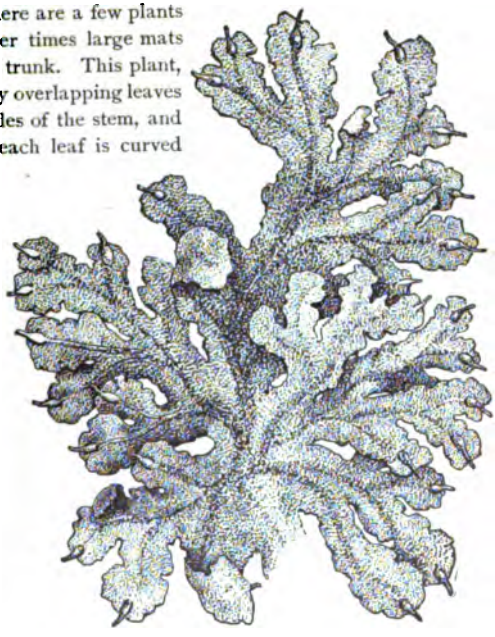

Fig. 270.
Thallus of a thalloid liverwort (blasia) showing lobed margin of the frond, intermediate between thalloid and foliose plant.

The larger plants are female, that is they bear archegonia, while the male plants, those which bear antheridia, are smaller and the antheridia are borne on small lateral branches. The antheridia are borne in the axils of the leaves. Others of the leafy-stemmed liverworts live in damp situations. Some of these, as Cephalozia, grow on damp rotten logs. Cephalozia is much more delicate, and the leaves are farther apart. It could not live in such dry situations where the frullania is sometimes found. If possible the two plants should be compared in order to see the adaptation in the structure and form to their environment.

499. Sporogonium of a foliose liverwort.—The sporogonium of the leafy-stemmed liverworts is well represented by that of several genera. We may take for this study the one illustrated

in fig. 274, but another will serve the purpose just as well. We note here that it consists of a rounded capsule borne aloft on a long stalk, the stalk being much longer proportionately than in marchantia. At maturity the capsule splits down into four

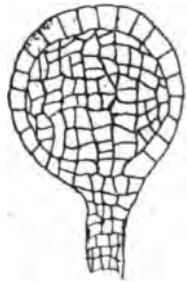

Fig. 272.
Antheridium of a foliose liverwort (jungermannia).

Fig. 271.
Foliose liverwort, male plant showing antheridia in axils of the leaves (a jungermannia).

Fig. 273.
Foliose liverwort, female plant with rhizoids.

quadrants, the wall forming four valves, which spread apart from the unequal drying of the cells, so that the spores are set free, as shown in fig. 276. Some of the cells inside of the capsule develop elaters here also as well as spores. These are illustrated in fig. 278.

500. In this plant we see that the sporophyte remains attached

to the gametophyte, and thus is dependent on it for sustenance. This is true of all the plants of this group. The sporophyte never becomes capable of an independent existence, and yet we see that it is becoming larger and more highly differentiated than in the simple riccia.

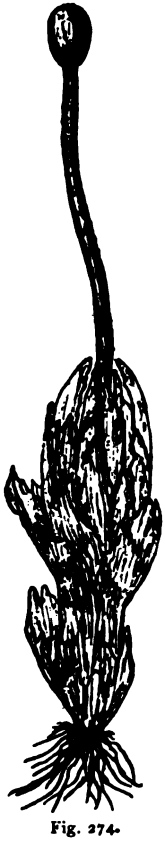

Fig. 274.

Fruiting plant of a foliose liverwort (jungermannia). Leafy part s the gametophyte; stalk and capsule is the sporophyte (sporogonium in the bryophytes).

Fig. 275.

Opening capsule showing escape of spores and elaters.

Fig. 276.

Capsule parted down to the stalk.

Fig. 277.

Four spores from mother cell held in a group.

Fig. 278.

Elaters, at left showing the two spiral marks, at right a branched elater.

Figs. 275–278.—Sporogonium of liverwort (jungermannia) opening by splitting into four parts, showing details of elaters and spores.

The Horned Liverworts.*

501. The horned liverworts take their name from the shape of the sporogonium. This is long, slender, cylindrical, pointed, and very slightly curved, suggesting the shape of a minute horn. Anthoceros is one of the most common and widely distributed species. The plant grows on damp soil or on mud.

Anthoceros.

502. The gametophyte.—The gametophyte is thalloid. It is thin, flattened, green, irregularly ribbon-shaped and branched. It lies on the soil and is more or less crisped or wavy, or curled, the edges nearly plane, or somewhat irregular, and with minute lobes, or notches, especially near the growing end. The general form and branching can be seen in fig. 279. Where the plants are much crowded the thallus is more irregular, and often possesses numerous small lateral branches in addition to the main lobes. Upon the under side are the slender rhizoids, which attach to the soil. With a hand lens there can be seen also upon the under side small dark, rounded and thickened spots, where an alga (nostoc) is located.

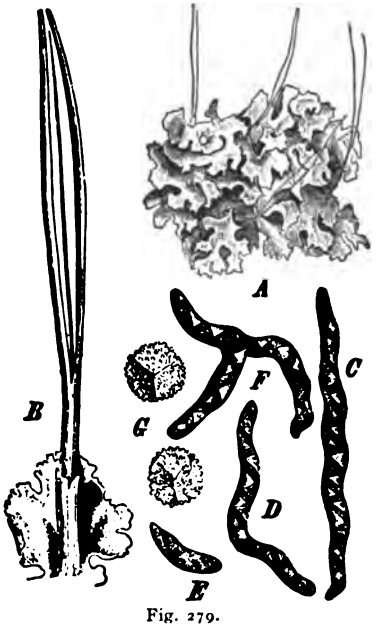

Fig. 279.

Anthoceros gracilis. *A*, several gametophytes, on which sporangia have developed, *B*, an enlarged sporogonium, showing its elongated character and dehiscence by two valves, leaving exposed the slender columella on the surface of which are the spores, *C*, *D*, *E*, *F*, elaters of various forms, *G*, spores. (After Schiffner.)

Sexual Organs of Anthoceros.

502. The sexual organs of anthoceros differ considerably from those of the other liverworts studied. In the first place they are immersed in the true tissue of the thallus, i.e., they do not project above the surface.

503. Antheridia.—The antheridium arises from an internal cell of the thallus, a cell just below the upper surface. This cell develops usually a

* May be used as an alternate study for marchantia.

group of antheridia which lie in a cavity formed around this cell as the thallus continues to grow. They are situated along the middle line of the thallus, and can be seen by making a section in this direction. The antheridia are oval or rounded, have a wall of one layer of cells which contains the sperm cells, and each antheridium has a slender stalk. The sperms are like those of the true liverworts.

504. Archegonia.—The archegonia are also borne along the middle line of the thallus. Each one arises at an early stage in the development of the tissue of the thallus from a superficial cell, but the archegonium does not project above the surface. The venter therefore which contains the egg is deep down in the thallus, the wall of the neck is formed from cells indistinguishable from the adjoining cells of the thallus and opens at the surface.

Sporophyte of Anthoceros.

505. The Sporogonium.—The sporogonium is developed from the fertilized egg, fertilization resulting of course from the fusion of one of the sperms with the nucleus of the egg. From the lower part of the embryo certain cells elongate and push out like rhizoids into the thallus (gametophyte), but never reach the outside so that the sporogonium derives its nutriment from the gametophyte in a parasitic manner like the true liverworts. It is surrounded at the base by a sheath, an outgrowth of the gametophyte.

506. Growing point of the sporogonium.—A remarkable thing about the sporogonium of anthoceros, and its relatives, is that the growing point instead of being situated at the free end is located near the base, just above the nourishing foot. Thus the upper part of the sporogonium is older. In the old sporogonia there may be ripe spores near the free end, young ones near the middle, and undifferentiated growing tissue near the base. A longitudinal section of a sporogonium just as the spores are ripening will show this.

507. Structure of the sporogonium.—A longitudinal section of the sporogonium shows that the spore-bearing tissue occupies a comparatively small portion of the sporogonium. In the section there is a narrow layer (two cells thick) on either side and joined at the top. In the entire sporogonium this fertile tissue is in the shape of an inverted test-tube situated inside of the sporogonium. The wall of the sporogonium is about four cells thick. The sterile tissue inside of the spore-bearing tube is the *columella*. The cells of the wall contain chlorophyll, and there are true stomata with guard cells in the epidermal layer.

508. Spores and elaters.—In the spore-bearing tissue there are two layers of cells (the archesporium). Each cell is a potential mother-cell. The cells, however, of alternate tiers do not form spores. They elongate some-

what and are somewhat irregular and sometimes divide or branch. They are supposed to represent rudimentary *elaters*. The cells in the other tiers are actual mother-cells, and each one forms four spores.

509. The sporophyte of anthoceros represents the highest type found in the liverworts. The spongy green parenchyma forming the wall, with the stomata in the epidermal layer, fits this tissue for the process of photosynthesis, so that this part of the sporophyte functions as the green leaf of the seed plants. It has been suggested by some that if the rhizoids on the nourishing foot could only extend outside and anchor in the soil, the sporophyte of anthoceros could live an independent existence. But we see that it stops short of that.

Classification of the Liverworts.

CLASS HEPATICÆ.

510. Order Marchantiales.*—There are two families represented in the United States.

Family Ricciaceæ, including Riccia and Ricciocarpus.

Family Marchantiaceæ, including Marchantia, Fegatella (= Conocephalus), Fimbriaria, Targionia, etc.

511. Order Jungermanniales.*—There are two subdivisions of this order. *The Anacrogynæ* include chiefly thalloid forms with continued apical growth, the archegonia back of the apical cell. Examples: Blasia, Aneura, Pellia, etc.

The Acrogynæ include chiefly foliose forms, the archegonia arising from the apical cell and in such cases interrupting apical growth. Examples: Cephalozia, Frullania, Bazzania, Jungermannia, Ptilidium, Porella, etc.

CLASS ANTHOCEROTES

512. The Anthocerotes have formerly been placed with the Hepaticæ as an order. But because of their wide divergence from the other liverworts in the development of the sexual organs, and especially in the structure of the sporophyte, they are now by some separated as a distinct class. There is one order.

Order Anthocerotales.* — This includes one family (Anthocerotaceæ) with Anthoceros and Notothylas in Europe and North America, and Dendroceros in the tropics. The latter is epiphytic.

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* As subclass in Engler and Prantl.

CHAPTER XXV.

MOSSES (MUSCI).

513. We are now ready to take up the more careful study of the moss plant. There are a great many kinds of mosses, and they differ greatly from each other in the finer details of structure. Yet there are certain general resemblances which make it convenient to take for study almost any one of the common species in a neighborhood, which forms abundant fruit. Some, however, are more suited to a first study than others. (Polytrichum and funaria are good mosses to study.)

514. Mnium.—We will select here the plant shown in fig. 280. This is known as a mnium (M. affine), and one or another of the species of mnium can be obtained without much difficulty. The mosses, as we have already learned, possess an axis (stem) and leaf-like expansions, so that they are leafy-stemmed plants also. Certain of the branches of the mnium stand upright, or nearly so, and the leaves are all of the same size at any given point on the stem, as seen in the figure. There are three rows of these leaves, and this is true of most of the mosses.

515. The mnium plants usually form quite extensive and pretty mats of green in shady moist woods or ravines. Here and there among the erect stems are prostrate ones, with two rows of prominent leaves so arranged that it reminds one of some of the leafy-stemmed liverworts. If we examine some of the leaves of the mnium we see that the greater part of the leaf consists of a single layer of green cells, just as is the case in the leafy-stemmed liverworts. But along the middle line is a thicker layer, so that it forms a distinct midrib. This is characteristic of the leaves

of mosses, and is one way in which they are separated from the leafy-stemmed liverworts, the latter never having a midrib.

516. The fruiting moss plant.—In fig. 280 is a moss plant "in fruit," as we say. Above the leafy stem a slender stalk bears the capsule, and in this capsule are borne the spores. The capsule then belongs to the *sporophyte phase* of the moss plant, and we should inquire whether the entire plant as we see it here is the sporophyte, or whether part of it is gametophyte. If a part of it is gametophyte and a part sporophyte, then where does the one end and the other begin? If we strip off the leaves at the end of the leafy stem, and make a longisection in the middle line, we should find that the stalk which bears the capsule is simply stuck into the end of the leafy stem, and is not organically connected with it. This is the dividing line, then, between the gametophyte and the sporophyte. We shall find that here the archegonium containing

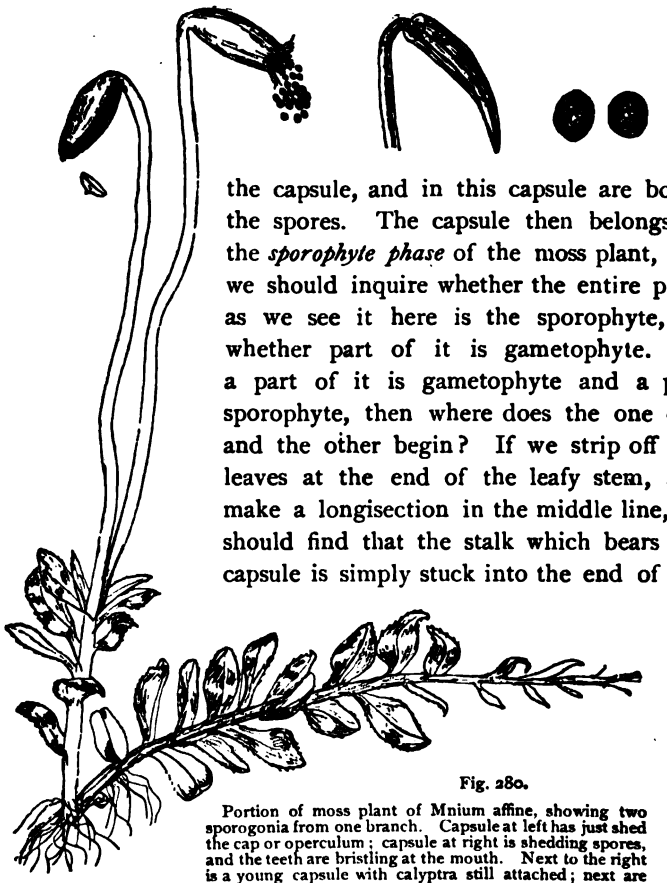

Fig. 280.

Portion of moss plant of Mnium affine, showing two sporogonia from one branch. Capsule at left has just shed the cap or operculum; capsule at right is shedding spores, and the teeth are bristling at the mouth. Next to the right is a young capsule with calyptra still attached; next are two spores enlarged.

the egg is borne, which is a surer way of determining the limits of the two phases of the plant.

517. The male and female moss plants.—The two plants of mnium shown in figs. 281, 282 are quite different, as one can easily see, and yet they belong to the same species. One is a female plant, while the other is a male plant. The sexual organs then in mnium, as in many others of the mosses, are borne on separate plants. The archegonia are borne at the end of the stem, and are protected by somewhat narrower leaves which closely overlap and are wrapped together. They are similar to the archegonia of the liverworts.

Fig. 281.

Female plant (gametophyte) of a moss (mnium), showing rhizoids below, and the tuft of leaves above which protect the archegonia.

Fig. 282.

Male plant (gametophyte) of a moss (mnium) showing rhizoids below and the antheridia at the center above surrounded by the rosette of leaves.

The male plants of mnium are easily selected, since the leaves at the end of the stem form a broad rosette with the antheridia, and some sterile threads packed closely together in the center. The ends of the mass of antheridia can be seen with the naked eye, as shown in fig. 282. When the antheridia

are ripe, if we make a section through a cluster, or if we merely tease out some from the end with a needle in a drop of water on the slide, then prepare for examination with the microscope, we can see the form of the antheridia. They are somewhat clavate or elliptical in outline, as seen in fig. 284. Between them there stand short threads composed of several cells containing chlorophyll grains. These are sterile threads (paraphyses).

518. Sporogonium.—In fig. 280 we see illustrated a sporogonium of mnium, which is of course developed from the fertilized egg cell of the archegonium. There is a nearly cylindrical capsule, bent downward, and supported on a long

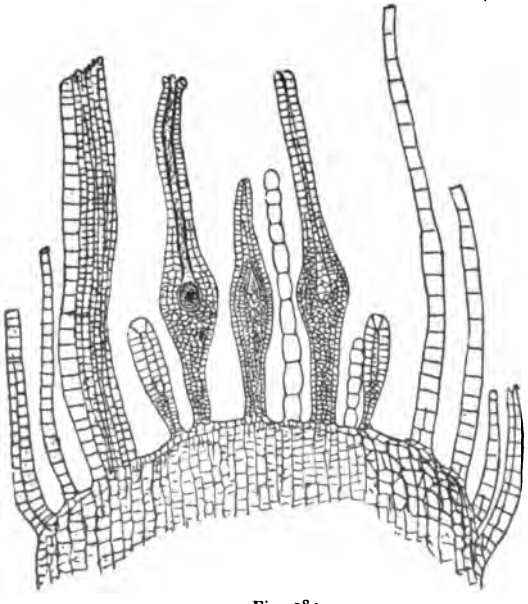

Fig. 283.

Section through end of stem of female plant of mnium, showing archegonia at the center. One archegonium shows the egg. On the sides are sections of the protecting leaves.

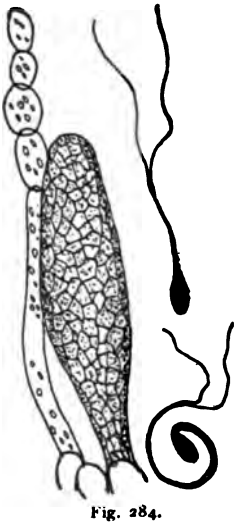

Fig. 284.

Antheridium of mnium with jointed paraphysis at the left; spermatozoids at the right.

slender stalk. Upon the capsule is a peculiar cap,* shaped like a ladle or spatula. This is the remnant of the old archegonium, which, for a time surrounded and protected the young embryo of the sporogonium, just as takes place in the liverworts. In most of the mosses this old remnant of the archegonium is borne aloft on the capsule as a cap, while in the liverworts it is thrown to one side as the sporogonium elongates.

519. Structure of the moss capsule.—At the free end on the moss capsule

* Called the calyptra.

as shown in the case of mnium in fig. 280, after the remnant of the archegonium falls away, there is seen a conical lid which fits closely over the end. When the capsule is ripe this lid easily falls away, and can be brushed off so that it is necessary to handle the plants with care if it is desired to preserve this for study.

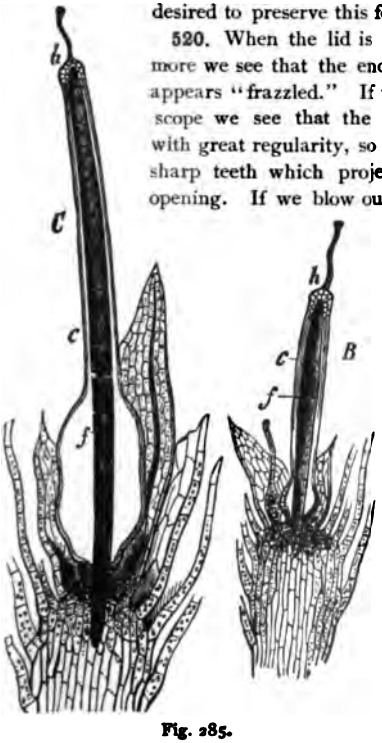

Fig. 285.

Two different stages of young sporogonium of a moss, still within the archegonium and wedging their way into the tissue of the end of the stem. *h*, neck of archegonium; *f*, young sporogonium. This shows well the connection of the sporophyte with the gametophyte.

520. When the lid is brushed away as the capsule dries more we see that the end of the capsule covered by the lid appears "frazzled." If we examine this end with the microscope we see that the tissue of the capsule here is torn with great regularity, so that there are two rows of narrow, sharp teeth which project outward in a ring around the opening. If we blow our "breath" upon these teeth they will be seen to move, and as the moisture disappears and reappears in the teeth, they close and open the mouth of the capsule, so sensitive are they to the changes in the humidity of the air. In this way all of the spores are prevented to some extent from escaping from the capsule at one time.

521. Note. If we make a section longitudinal of the capsule of mnium, or some other moss, we find that the tissue which develops the spores is much more restricted than in the capsule of the liverworts which we have studied. The spore-bearing tissue is confined to a single layer which extends around the capsule some distance from the outside of the wall, so that a central cylinder is left of sterile tissue. This is the columella, and is present in nearly all the mosses. Each of the cells of the fertile layer divides into four spores.

522. Development of the sporogonium.—The egg cell after fertilization divides by a wall crosswise to the axis of the archegonium. Each of these cells continues to divide for a time, so that a cylinder pointed at both ends is formed. The lower end of this cylinder of tissue wedges its way down through the base of the archegonium into the tissue of the end of the moss stem as shown in fig. 285. This forms the foot through which the nutrient

materials are passed from the gametophyte to the sporogonium. The upper part continues to grow, and finally the upper end differentiates into the mature capsule.

523. Protonema of the moss.—When the spores of a moss germinate they form a thread-like body, with chlorophyll. This thread becomes branched, and sometimes quite extended tangles of these threads are formed. This is called the protonema, that is *first thread.* The older threads become finally brown, while the later ones are green. From this protonema at certain points buds appear which divide by close oblique walls. From these buds the leafy stem of the moss plant grows. Threads similar to these protonemal threads now grow out from the leafy stem, to form the rhizoids. These supply the moss plant with nutriment, and now the protonema usually dies, though in some few species it persists for long periods.

Classification of the Mosses.

CLASS MUSCINEÆ (MUSCI).

524. Order Sphagnales.*—This order includes the peat mosses. There is but one family (Sphagnaceæ) and but a single genus (Sphagnum). The peat mosses are widely distributed over the globe, chiefly occurring in moors, or "bogs," usually low ground around the shores of lakes, ponds, or along streams, but they often occur on wet dripping rocks in cool shady places. Small ponds are sometimes filled in by their growth. As the sphagnum growing in such an abundance of water only partially decays, "ground" is built up rather rapidly, and the sphagnum remains are known as "peat." This "ground"-building peculiarity of sphagnum sometimes enables the plant (often in conjunction with others) to fill in ponds completely. (See Atoll Moor, Chapter LV.)

The gametophyte of sphagnum, like that of all the mosses, is dimorphic, but the first part (or protonema) which develops from the spores is thalloid, and therefore more like the thallose liverworts. The leafy axis (or gametophore) which develops from the thalloid form is very characteristic (see Chapter LV).

The archegonia are borne on the free end of the main axis, while the antheridia are borne on short branches which are brightly colored, red, yellow, etc. The sporophyte (sporogonium) is globose and possesses a broad foot anchored in the end of a naked prolongation of the end of the leafy gametophore. This naked prolongation of the gametophore looks like the stalk of the sporogonium, but a study of its connection with the sporogonium shows that it is part of the gametophyte, which is only developed after the fertilization of the egg in the archegonium. In the sporogonium there is a short columella, and the archesporium is in the form of an inverted cup.

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* As subclass in Engler and Prantl.

525. Order Andreæales.*—This order includes the single genus Andreæa. The plants are small but form extensive mats, growing on rocks in arctic or alpine regions usually. They are sometimes found in great abundance on bare, rather dry rocks on mountains. The protonema is somewhat thalloid. The sporogonium opens by splitting longitudinally into four valves. An elongated columella is present so that the archesporium is shaped like an inverted test-tube.

526. Order Archidiales.*—This order contains the single genus Archidium, and by some is placed as an aberrant genus in the Bryales. There is no columella in the simple sporogonium. The archesporium occupies all the internal part of the sporogonium, some cells being fertile and others sterile.

527. Order Bryales.*—These include the higher mosses, and a very large number of genera and species. The protonema is filamentous and branched except in a few forms where it is partly thalloid as in Tetraphis (= Georgia). (Tetraphis pellucida is a common moss on very rotten logs. The capsule has four prominent teeth.) In a few of the lower genera (Phascum, Pleuridium, etc.) the capsule opens irregularly, but in the larger number the capsule opens by a lid (operculum). A cylindrical columella is present, and the archesporium is in the form of a tube open at both ends. (Examples: Polytrichum, Bryum, Mnium, Hypnum, etc.)

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* As subclass in Engler and Prantl.

528. TABLE SHOWING RELATION OF GAMETOPHYTE AND SPOROPHYTE IN THE LIVERWORTS AND MOSSES.

	GAMETOPHYTE. (Prominent part of the plant. Leads an independent existence.)				SPOROPHYTE. (Attached to gametophyte and dependent on it for nourishment.)			
	Vegetative Stage.	Vegetative Multiplication.	Sexual Organs.		Beginning of Sporophyte.	Sterile Part.	Fertile Part	Beginning of Gametophyte.
Riccia.	Thallus flattened, ribbon-like, forked, or nearly circular.	Sometimes by branching and dying away of older parts.	Immersed by surrounding, upward growth of thallus. Antheridia, with spermatozoids.	Archegonia, with egg in each.	Fertilized egg. (Develops sporogonium.)	Wall of sporogonium, of one-layer cells.	Central mass (archesporium) develops	Spores.
Marchantia.	Thallus flattened, ribbon-like, forked, male and female plants bear gametophores.	By dying away of older parts, and by gemmæ.	Borne on special receptacles on different plants. Antheridia, with spermatozoids, borne on antheridiophores, or male gametophores	Archegonia, borne on female gametophore (or archegoniophore), each with an egg.	Fertilized egg. (Develops sporogonium.)	Sterile part of stalked capsule is stalk, wall of capsule of several layers, elaters.	Central part of capsule (archesporium) develops..... and elaters.	Spores.
Jungermannia (or Cephalozia, Porella, etc.)	A plant with apparent leaves and stem; margins of thallus have become cut into lobes. Male and female plants.	By dying away of older parts.	On different plants. Antheridia, with spermatozoids, in axils of leaves of male plant.	Archegonia, each with egg, on female plant.	Fertilized egg. (Develops sporogonium.)	Sterile part of stalked capsule is stalk, wall of capsule of several layers, elaters	Central part of capsule (archesporium) develops ..... and elaters.	Spores.
Mosses. {Mnium, Funaria, Polytrichum, etc.	Plant with apparent leafy axis, 3 rows of leaves (similar to jungermannia), borne on an earlier protonemal stage. Male and female plants.	By branching, by growth of protonema from axis, leaves, or even sporogonium. (In some genera by gemmæ.)	On different plants. Antheridia, with spermatozoids, at end of stem of male plant.	Archegonia, each with egg, on female plant. (Calyptra found on sporogonium is remnant of archegonium.)	Fertilized egg. (Develops sporogonium.)	Sterile part of stalked capsule is stalk, wall of capsule of several layers, columella, lid, teeth, etc., of the highly specialized capsule.	Cylindrical layer of cells around columella is the archesporium; it develops	Spores.

CHAPTER XXVI.

FERNS.

529. In taking up the study of the ferns we find plants which are very beautiful objects of nature and thus have always attracted the interest of those who love the beauties of nature. But they are also very interesting to the student, because of certain remarkable peculiarities of the structure of the fruit bodies, and especially because of the intermediate position which they occupy within the plant kingdom, representing in the two phases of their development the primitive type of plant life on the one hand, and on the other the modern type. We will begin our study of the ferns by taking that form which is the more prominent, the fern plant itself.

530. The Christmas fern.—One of the ferns which is very common in the Northern States, and occurs in rocky banks and woods, is the well-known Christmas fern (Aspidium acrostichoides) shown in fig. 286. The leaves are the most prominent part of the plant, as is the case with most if not all our native ferns. The stem is very short and for the most part under the surface of the ground, while the leaves arise very close together, and thus form a rosette as they rise and gracefully bend outward. The leaf is elongate and reminds one somewhat of a plume with the pinnæ extending in two rows on opposite sides of the midrib. These pinnæ alternate with one another, and at the base of each pinna is a little spur which projects upward from the upper edge. Such a leaf is said to be pinnate. While all the leaves have the same general outline, we notice that certain ones, especially those toward the center of the rosette, are much narrower from the

middle portion toward the end. This is because of the shorter pinnæ here.

531. Fruit "dots" (sorus, indusium).—If we examine the under side of such short pinnæ of the Christmas fern we see that there are two rows of small circular dots, one row on either side of the pinna. These are called the "fruit dots," or sori (a single one is a sorus). If we examine it with a low power of the microscope, or with a pocket lens, we see that there is a circular disk which covers more or less completely very minute objects, usually the ends of the latter projecting just beyond the edge if they are mature. This circular disk is what is called the *indusium*, and it is a special outgrowth of the epidermis of the leaf here for the protection of the spore-cases. These minute objects underneath are the fruit bodies, which in the case of the ferns and their allies are called *sporangia*. This indusium in the case of the Christmas fern, and also in some others, is attached to the leaf by means of a short slender stalk

Fig. 286.
Christmas fern (Aspidium acrostichoides).

which is fastened to the middle of the under side of this shield, as seen in cross section in fig. 292.

532. Sporangia. — If we section through the leaf at one of the fruit dots, or if we tease off some of the sporangia so that the stalks are still attached, and examine them with the microscope, we can see the form and structure of these peculiar bodies. Different views of a sporangium are shown in fig. 293. The slender portion is the stalk, and the larger part is the spore-case proper. We should examine the structure of this spore-case quite carefully, since it will help us to understand better than we otherwise could the remarkable operations which it performs in scattering the spores.

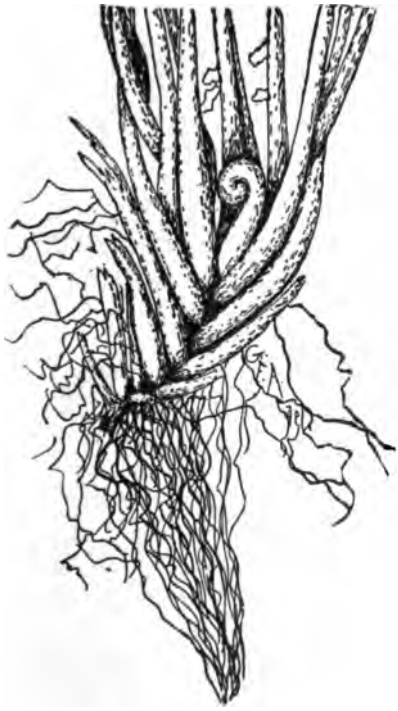

Fig 287.

Rhizome with bases of leaves, and roots of the Christmas fern.

533. Structure of a sporangium. — If we examine one of the sporangia in side view as shown in fig. 293, we note a prominent row of cells which extend around the margin of the dorsal edge from near the attachment of the stalk to the upper front angle. The cells are prominent because of the thick inner walls, and the thick radial walls which are perpendicular to the inner walls. The walls on the back of this row and on its sides are very thin and membranous. We should make this out carefully, for the structure of these cells is especially adapted to a special function which they perform. This row of cells

is termed the *annulus*, which means a little ring. While this is not a complete ring, in some other ferns the ring is nearly complete.

534. In the front of the sporangium is another peculiar group

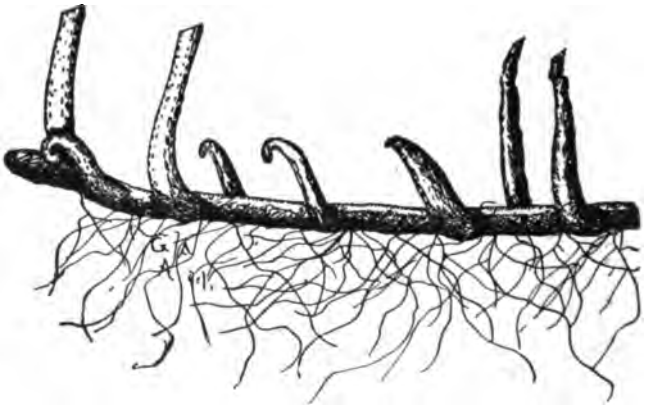

Fig. 288.
Rhizome of sensitive fern (Onoclea sensibilis).

of cells. Two of the longer ones resemble the lips of some creature, and since the sporangium opens between them they are sometimes termed the lip cells. These lip cells are connected with the upper end of the annulus on one side and with the upper end of the stalk on the other side by thin-walled cells, which may be termed connective cells, since they hold each lip cell to its part of the opening sporangium. The cells on the side of the sporangium are also thin-walled. If we now examine a sporangium from the back, or dorsal edge as we say, it will appear as in the left-hand figure. Here we can see how very prominent the annulus is. It projects beyond the surface of the other cells of the sporangium. The spores are contained inside this case.

Fig. 289.
Under side of pinna of Aspidium spinulosum showing fruit dots (sori).

535. Opening of the sporangium and dispersion of the spores.—If we take some fresh fruiting leaves of the Christmas fern, or of any one of many of the species of the true ferns just at the ripening of the spores, and place a portion of it on a piece of white paper in a dry room, in a very short time we shall see that the paper is being dusted with minute brown objects which fly out from the leaf. Now if we take a portion of the same leaf and place it under the low power of the microscope, so that the full rounded sporangia can be seen, in a short time we note that the sporangium opens, the upper half curls backward as

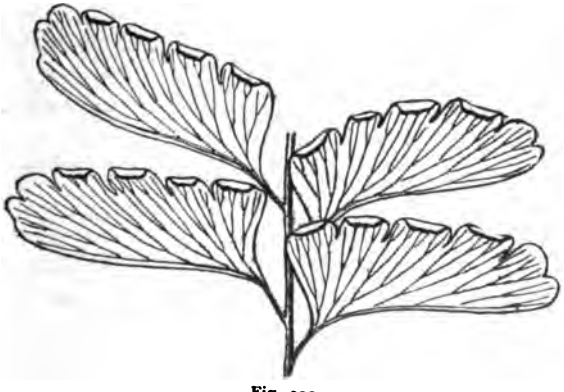

Fig. 290.
Four pinnæ of adiantum, showing recurved margins which cover the sporangia.

shown in fig. 294, and soon it snaps quickly, to near its former position, and the spores are at the same time thrown for a considerable distance. This movement can sometimes be seen with the aid of a good hand lens.

536. How does this opening and snapping of the sporangium take place?—We are now more curious than ever to see just how this opening and snapping of the sporangium takes place. We should now mount some of the fresh sporangia in water and cover with a cover glass for microscopic examination. A drop of glycerine should be placed at one side of the cover glass on the slip so that the edge of the glycerine will come in touch with the water. Now as one looks through the microscope to watch the

sporangia, the water should be drawn from under the cover glass with the aid of some bibulous paper, like filter paper, placed at the edge of the cover glass on the opposite side from the glycerine. As the glycerine takes the place of the water around the sporangia it draws the water out of the cells of the annulus, just as it took the water out of the cells of the spirogyra as we learned some time ago. As the water is drawn out of these cells there is produced a pressure from without, the atmospheric pressure upon the glycerine. This causes the walls of these cells of the annulus to bend inward, because, as we have already learned, the glycerine does not pass through the walls nearly so fast as the water comes out.

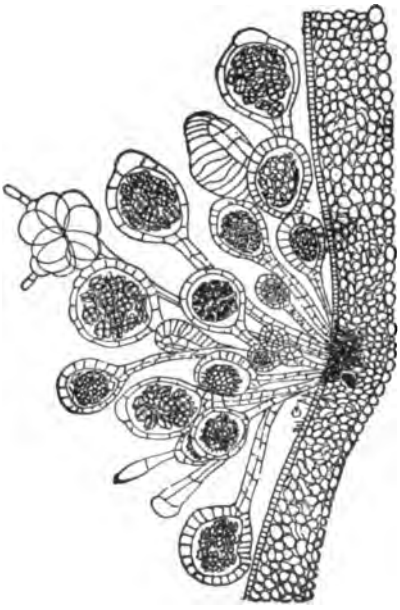

Fig. 291.
Section through sorus of Polypodium vulgare showing different stages of sporangium, and one multicellular capitate hair.

537. Now the structure of the cells of this annulus, as we have seen, is such that the inner walls and the perpendicular

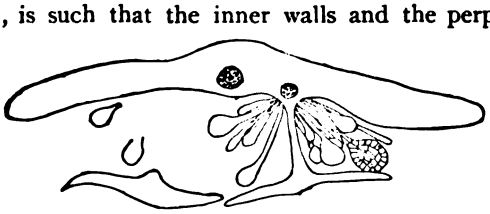

Fig. 292.
Section through sorus and shield-shaped indusium of aspidium.

walls are stout, and consequently they do not bend or collapse when this pressure is brought to bear on the outside of the cells.

The thin membranous walls on the back (dorsal walls) and on the sides of the annulus, however, yield readily to the pressure and bend inward. This, as we can readily see, pulls on the ends of each of the perpendicular walls drawing them closer together. This shortens the outer surface of the annulus and causes it to first assume a nearly straight position, then curve backward until it quite or nearly becomes doubled on itself. The sporangium

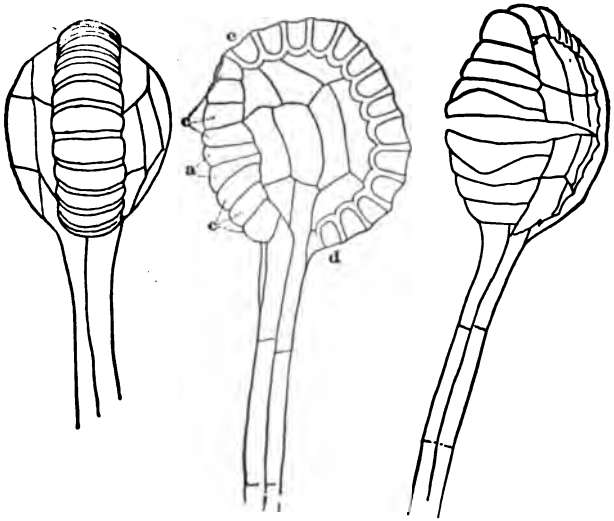

Fig. 293.
Rear, side, and front views of fern sporangium. *d*, *e*, annulus; *a*, lip cells.

opens between the lip cells on the front and the lateral walls of the sporangium are torn directly across. The greater mass of spores are thus held in the upper end of the open sporangium, and when the annulus has nearly doubled on itself it suddenly snaps back again in position. While treating with the glycerine we can see all this movement take place. Each cell of the annulus acts independently, but often they all act in concert. When they do not all act in concert, some of them snap sooner than others, and this causes the annulus to snap in segments.

538. The movements of the sporangium can take place in old and dried material.—If we have no fresh material to study

the sporangium with, we can use dried material, for the movements of the sporangia can be well seen in dried material, provided it was collected at about the time the sporangia are mature, that is at maturity, or soon afterward. We take some of the dry sporangia (or we may wash the glycerine off those which we have just studied) and mount them in water, and quickly examine

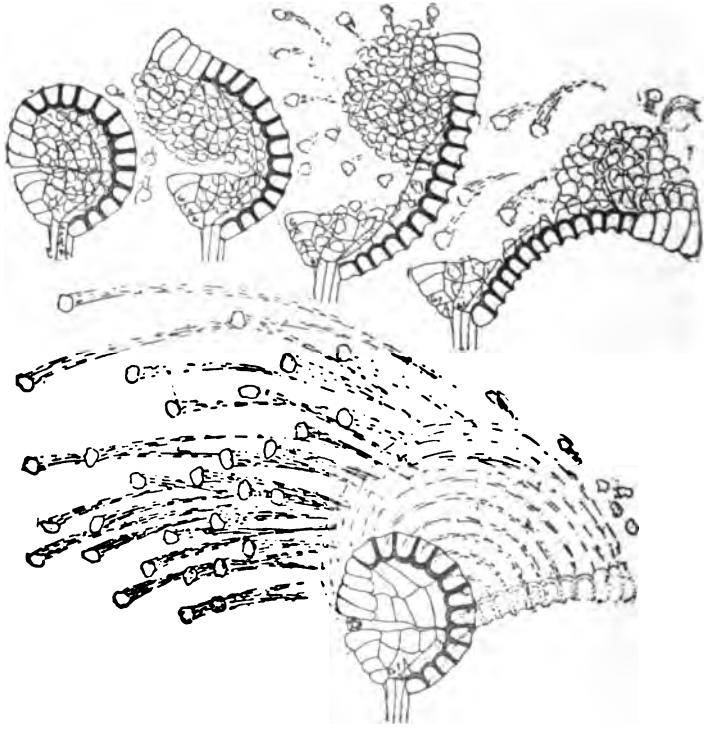

Fig. 294.

Dispersion of spores from sporangium of Aspidium acrostichoides, showing different stages in the opening and snapping of the annulus.

them with a microscope. We notice that in each cell of the annulus there is a small sphere of some gas. The water which bathes the walls of the annulus is absorbed by some substance inside these cells. This we can see because of the fact that this sphere of gas becomes smaller and smaller until it is only a mere

dot, when it disappears in a twinkling. The water has been taken in under such pressure that it has absorbed all the gas, and the farther pressure in most cases closes the partly opened sporangium more completely.

539. Now we should add glycerine again and draw out the water, watching the sporangia at the same time. We see that the sporangia which have opened and snapped once will do it again. And so they may be made to go through this operation several times in succession. We should now note carefully the annulus, that is after the sporangia have opened by the use of glycerine. So soon as they have snapped in the glycerine we can see those minute spheres of gas again, and since there was no air on the outside of the sporangia, but only glycerine, this gas must, it is reasoned, have been given up by the water before it was all drawn out of the cells.

540. The common polypody.—We may now take up a few other ferns for study. Another common fern is the polypody, one or more species of which have a very wide distribution. The stem of this fern is also not usually seen, but is covered with the leaves, except in the case of those species which grow on the surface of rocks. The stem is slender and prostrate, and is covered with numerous brown scales. The leaves are pinnate in this fern also, but we find no difference between the fertile and sterile leaves (except in some rare cases). The fruit-dots occupy much the same positions on the under side of the leaf that they do in the Christmas fern, but we cannot find any indusium. In the place of an indusium are club-shaped hairs as shown in fig. 291. The enlarged ends of these clubs reaching beyond the sporangia give some protection to them when they are young.

541. Other ferns.—We might examine a series of ferns to see how different they are in respect to the position which the fruit dots occupy on the leaf. The common brake, which sometimes covers extensive areas and becomes a troublesome weed, has a stout and smooth underground stem (rhizome) which is often 12 to 20 *cm* beneath the surface of the soil. There is a long leaf stalk, which bears the lamina, the latter being several times pinnate. The margins of the fertile pinnæ are inrolled, and the sporangia are found protected underneath in this long sorus along the margin of the pinna. The beautiful maidenhair fern and its relatives have obovate pinnæ, and the sori are situated in the same positions as in the brake. In other ferns, as the walking fern, the sori are borne along by the side of the veins of the leaf.

542. Opening of the leaves of ferns.—The leaves of ferns open in a peculiar manner. The tip of the leaf is the last portion developed, and the growing

leaf appears as if it was rolled up as in fig. 287 of the Christmas fern. As the leaf elongates this portion unrolls.

543. Longevity of ferns.—Most ferns live from year to year, by growth adding to the advance of the stem, while by decay of the older parts the stem shortens up behind. The leaves are short-lived, usually dying down each year, and a new set arising from the growing end of the stem. Often one can see just back or below the new leaves the old dead ones of the past season, and farther back the remains of the petioles of still older leaves.

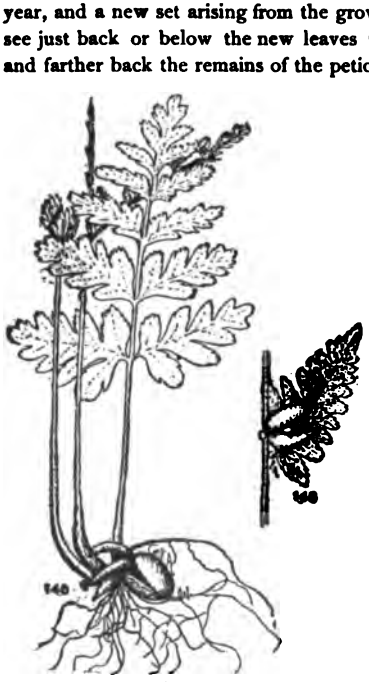

Fig. 295.

Cystopteris bulbifera, young plant growing from bulb. At right is young bulb in axil of pinna of leaf.

544. Budding of ferns. — A few ferns produce what are called bulbils or bulblets on the leaves. One of these, which is found throughout the greater part of the eastern United States, is the bladder fern (Cystopteris bulbifera), which grows in shady rocky places. The long graceful delicate leaves form in the axils of the pinnæ, especially near the end of the leaf, small oval bulbs as shown in fig. 295. If we examine one of these bladder-like bulbs we see that the bulk of it is made up of short thick fleshy leaves, smaller ones appearing between the outer ones at the smaller end of the bulb. This bulb contains a stem, young root, and several pairs of these fleshy leaves. They easily fall to the ground or rocks, where, with the abundant moisture usually present in localities where the fern is found, the bulb grows until the roots attach the plant to the soil or in the crevices of the rocks. A young plant growing from one of these bulbils is shown in fig. 295.

545. Greenhouse ferns.—Some of the ferns grown in conservatories have similar bulblets. Fig. 296 represents one of these which is found abundantly on the leaves of Asplenium bulbiferum. These bulbils have leaves which are very similar to the ordinary leaf except that they are smaller. The bulbs are also much more firmly attached to the leaf, so that they do not readily fall away.

546. Plant conservatories usually furnish a number of very interesting ferns, and one should attempt to make the acquaintance of some of them, for

here one has an opportunity during the winter season not only to observe these interesting plants, but also to obtain material for study. In the tree ferns which often are seen growing in such places we see examples of the massive trunks and leaves of some of the tropical species.

547. The fern plant is a sporophyte.—We have now studied the fern plant, as we call it, and we have found it to represent the spore-bearing phase of the plant, that is the *sporophyte* (corresponding to the sporogonium of the liverworts and mosses).

548. Is there a gametophyte phase in ferns?—But in the sporophyte of the fern, which we should not forget is the fern plant, we have a striking advance upon the sporophyte of the liverworts and mosses. In the latter plants the sporophyte remained attached to the gametophyte, and derived its nourishment from it. In the ferns, as we see, the sporophyte has a root of its own, and is attached to the soil. Through the aid of root hairs of its own it takes up mineral solutions. It possesses also a true stem, and true leaves in which carbon conversion takes place. It is able to live independently, then. Does a gametophyte phase exist among the ferns? Or has it been lost? If it does exist, what is it like, and where does it grow? From what we have already learned we should expect to find the gametophyte begin with the germination of the spores which are developed on the sporophyte, that is on the fern plant itself. We should investigate this and see.

Fig. 296.
Bulbil growing from leaf of asplenium (*A*, bulbiferum).

CHAPTER XXVII.

FERNS CONTINUED.

Gametophyte of ferns.

549. Sexual stage of ferns.—We now wish to see what the sexual stage of the ferns is like. Judging from what we have found to take place in the liverworts and mosses we should infer

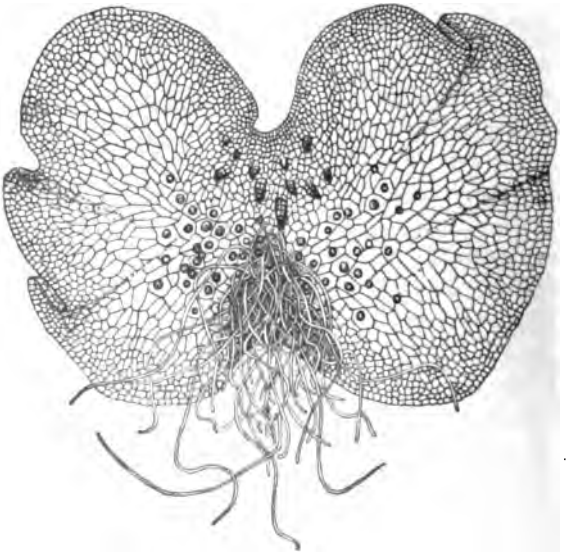

Fig. 297.

Prothallium of fern, under side, showing rhizoids, antheridia scattered among and near them, and the archegonia near the sinus.

that the form of the plant which bears the sexual organs is developed from the spores. This is true, and if we should examine old decaying logs, or decaying wood in damp places in the near

vicinity of ferns, we should probably find tiny, green, thin, heart-shaped growths, lying close to the substratum. These are also found quite frequently on the soil of pots in plant conservatories where ferns are grown. Gardeners also in conservatories usually sow fern spores to raise new fern plants, and usually one can find these heart-shaped growths on the surface of the soil where they have sown the spores. We may call the gardener to our aid in finding them in conservatories, or even in growing them for us if we cannot find them outside. In some cases they may be grown in an ordinary room by keeping the surfaces where they are growing moist, and the air also moist, by placing a glass bell jar over them.

Fig. 298.
Spore of Pteris serrulata showing the three-rayed elevation along the side of which the spore wall cracks during germination.

550. In fig. 297 is shown one of these growths enlarged. Upon the under side we see numerous thread-like outgrowths, the rhizoids, which attach the plant to the substratum, and which act as organs for the absorption of nourishment. The sexual organs are borne on the under side also, and we will study them later. This heart-shaped, flattened, thin, green plant is the *prothallium* of ferns, and we should now give it more careful study, beginning with the germination of the spores.

Fig. 299.
Spore of Aspidium acrostichoides with winged exospore.

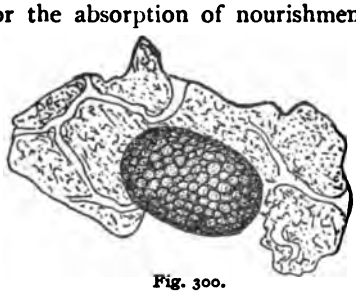

Fig. 300.
Spore crushed to remove exospore and show endospore.

551. Spores.—We can easily obtain material for the study of the spores of ferns. The spores vary in shape to some extent. Many of them are shaped like a three-sided pyramid. One of these is shown in fig. 298. The outer wall is roughened, and on one end are three elevated ridges which radiate from a given

point. A spore of the Christmas fern is shown in fig. 299. The outer wall here is more or less winged. At fig. 300 is a spore of the same species from which the outer wall has been crushed, showing that there is an inner wall also. If possible we should study the germination of the spores of some fern.

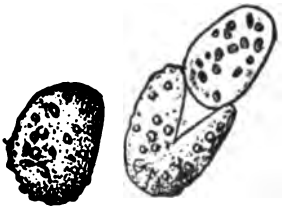

Fig. 301.
Spores of asplenium; exospore removed from the one at the right.

552. Germination of the spores. —After the spores have been sown for about one week to ten days we should mount a few in water for examination with the microscope in order to study the early stages. If germination has begun, we find that here and there are short slender green threads, in many cases attached to brownish bits, the old walls of the spores. Often one will sow the sporangia along with the spores, and in such cases there may be found a number of spores still within the old sporangium wall that are germinating, when they will appear as in fig. 302.

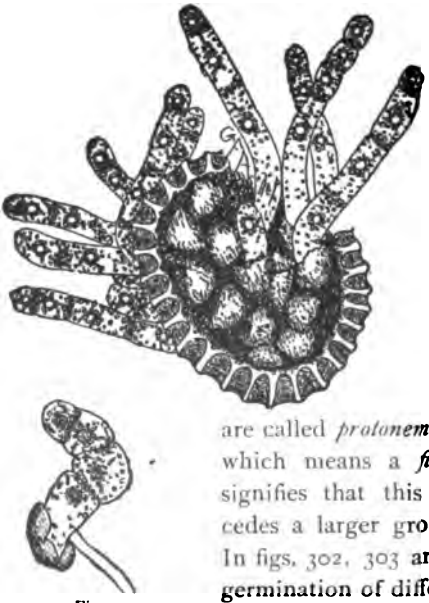

Fig. 302.
Germinating spores of Pteris aquilina still in the sporangium.

553. Protonema. — These short green threads are called *protonemal* threads, or ***protonema***, which means a ***first thread***, and it here signifies that this short thread only precedes a larger growth of the same object. In figs. 302, 303 are shown several stages of germination of different spores. Soon after the short germ tube emerges from the crack in the spore wall, it divides by the

formation of a cross wall, and as it increases in length other cross walls are formed. But very early in its growth we see that a slender outgrowth takes place from the cell nearest the old spore wall. This slender thread is colorless, and is not divided into cells. It is the first rhizoid, and serves both as an organ of attachment for the thread, and for taking up nutriment.

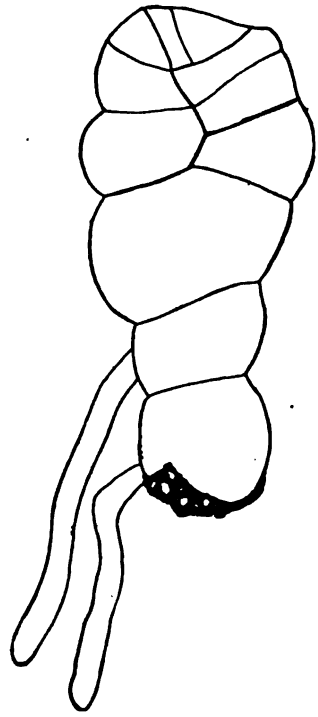

Fig. 303.
Young prothallium of a fern (niphobolus).

554. Prothallium.—Very soon, if the sowing has not been so crowded as to prevent the young plants from obtaining nutriment sufficient, we will see that the end of this protonema is broadening, as shown in fig. 303. This is done by the formation of the cell walls in different directions. It now continues to grow in this way, the end becoming broader and broader, and new rhizoids are formed from the under surface of the cells. The growing point remains at the middle of the advancing margin, and the cells which are cut off from either side, as they become old, widen out. In this way the "wings," or margins of the little, green, flattened body, are in advance of the growing point, and the object is more or less heart-shaped, as shown in fig. 297. Thus we see how the prothallium of ferns is formed.

555. Sexual organs of ferns.—If we take one of the prothallia of ferns which have grown from the sowings of fern spores, or one of those which may be often found growing on the soil

of pots in conservatories, mount it in water on a slip, with the under side uppermost, we can then examine it for the

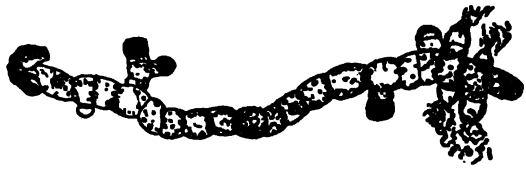

Fig. 304.

Male prothallium of a fern (niphobolus), in form of an alga or protonema. Spermatozoids escaping from antheridia.

sexual organs, for these are borne in most cases on the under side.

556. Antheridia.—If we search among the rhizoids we see small rounded elevations as shown in fig. 297 or 305 scat-

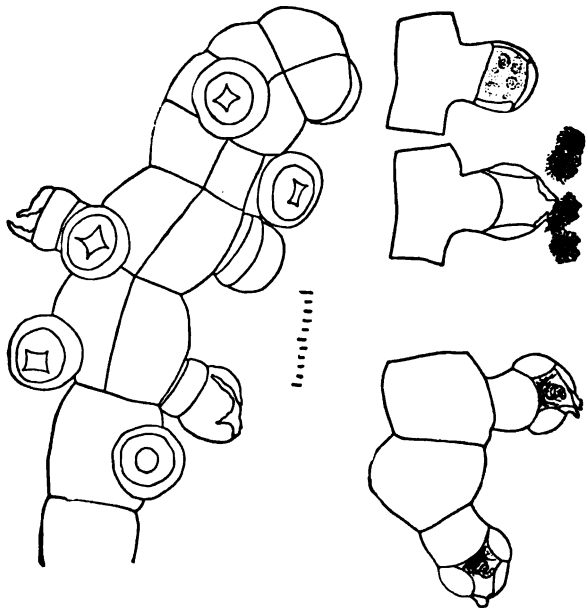

Fig. 305.

Male prothallium of fern (niphobolus), showing opened and unopened antheridia, section of unopened antheridium; spermatozoids escaping; spermatozoids which did not escape from the antheridium.

tered over this portion of the prothallium. These are the antheridia. If the prothallia have not been watered for a day or so, we may have an opportunity of seeing the spermatozoids coming out of the antheridium, for when the prothallia are freshly placed in water the cells of the antheridium absorb water. This presses on the contents of the antheridium and bursts the cap cell if the antheridium is ripe, and all the spermatozoids are shot out. We can see here that each one is shaped like a screw, with the coils at first close. But as the spermatozoid begins to move this coil opens somewhat and by the vibration of the long cilia which are on the smaller end it whirls away. In such preparations one may often see them spinning around for a long while, and it is only when they gradually come to rest that one can make out their form.

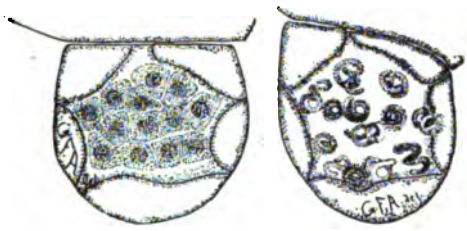

Fig. 306.
Section of antheridia showing sperm cells, and spermatozoids in the one at the right.

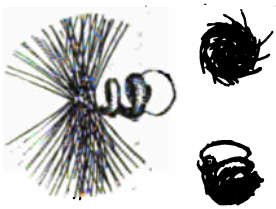

Fig. 307.
Different views of spermatozoids; in a quiet condition; in motion (Adiantum concinnum).

557. Archegonia.—If we now examine closely on the thicker part of the under surface of the prothallium, just back of the "sinus," we may see longer stout projections from the surface of the prothallium. These are shown in fig. 297. They are

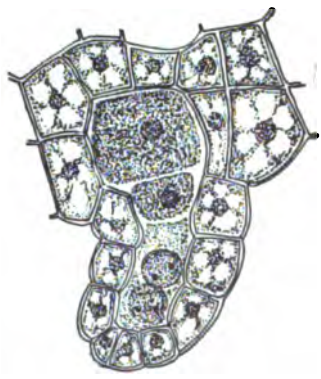

Fig. 308.
Archegonium of fern. Large cell in the venter is the egg, next is the ventral canal cell, and in the canal of the neck are two nuclei of the canal cell.

the archegonia. One of them in longisection is shown in fig. 308. It is flask-shaped, and the broader portion is sunk in the

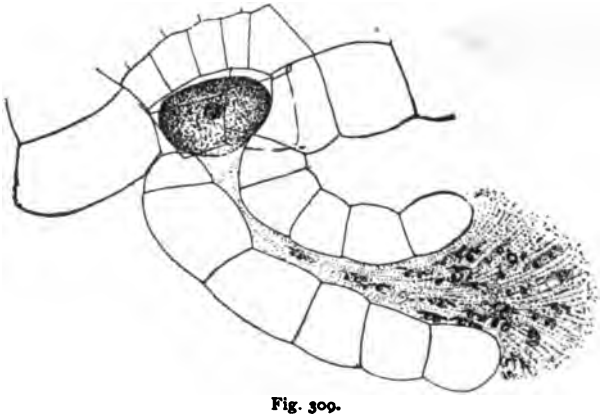

Fig. 309.

Mature and open archegonium of fern (Adiantum cuneatum) with spermatozoids making their way down through the slime to the egg.

tissue of the prothallium. The egg is in the larger part. The spermatozoids when they are swimming around over the under surface of the prothallium come near the neck, and here they are caught in the viscid substance which has oozed out of the canal of the archegonium. From here they slowly swim down the canal, and finally one sinks into the egg, fuses with the nucleus of the latter, and the egg is then fertilized. It is now ready to grow and develop into the fern plant. This brings us back to the sporophyte, which begins with the fertilized egg.

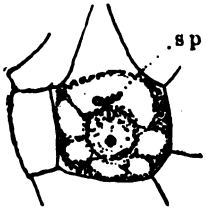

Fig. 310.

Fertilization in a fern (Marattia). *sp*, spermatozoid fusing with the nucleus of the egg. (After Campbell.)

Sporophyte.

558. Embryo.—The egg first divides into two cells as shown in fig. 228, then into four. Now from each one of these quandrants of the embryo a definite part of the plant develops, from one the first leaf, from one the stem, from one the root, and from the other the organ which is called the foot, and which

attaches the embryo to the prothallium, and transports nourishment for the embryo until it can become attached to the soil and lead an independent existence. During this time the wall of the archegonium grows somewhat to accommodate the increase in size of the embryo, as shown in figs. 312, 313. But soon the wall of the archegonium is ruptured and the embryo emerges, the root attaches itself to the soil, and soon the prothallium dies.

The embryo is first on the under side of the prothallium, and the first leaf

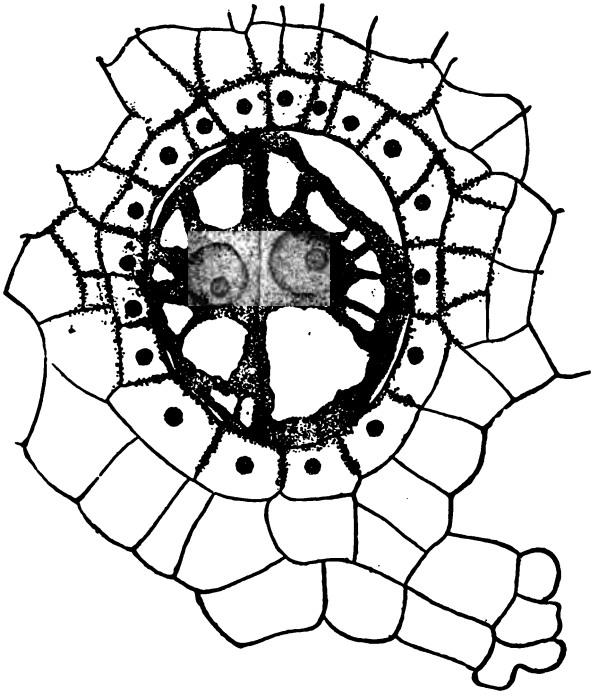

Fig. 311.
Two-celled embryo of Pteris serrulata. Remnant of archegonium neck below.

and the stem curves upward between the lobes of the heart-shaped body, and then grows upright as shown in fig. 314. Usually only one embryo is formed on a single prothallium, but in one case I found a prothallium with two well-formed embryos, which are figured in 315.

559. Comparison of ferns with liverworts and mosses.—In the ferns then we have reached a remarkable condition of things as compared with that which we found in the mosses and liverworts. In the mosses and liverworts

the sexual phase of the plant (gametophyte) was the prominent one, and consisted of either a thallus or a leafy axis, but in either case it bore the sexual organs and led an independent existence; that is it was capable of obtaining its nourishment from the soil or water by means of organs of absorption belonging to itself, and it also performed the office of photosynthesis.

560. The spore-bearing phase (sporophyte) of the liverworts and mosses, on the other hand, is quite small as compared with the sexual stage, and it is

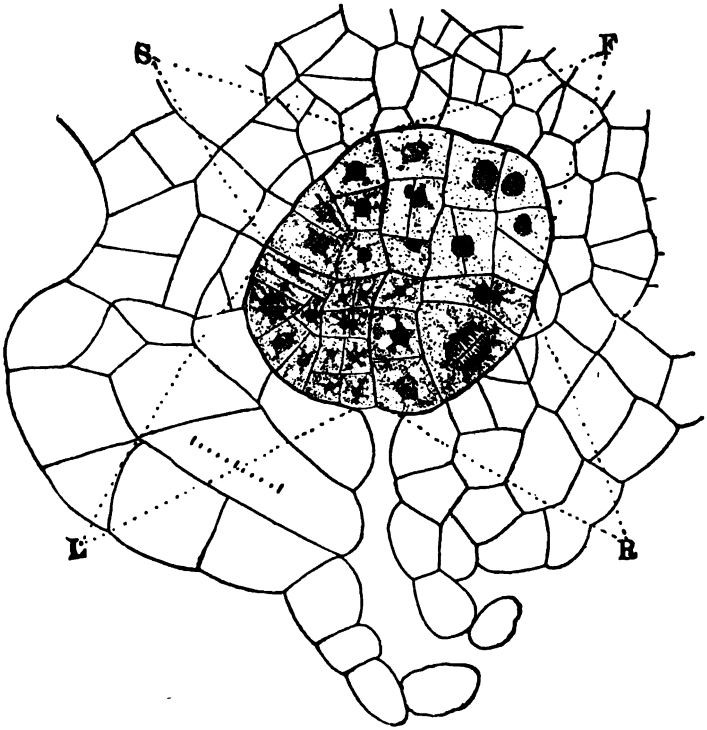

Fig. 312.

Young embryo of fern (Adiantum concinnum) in enlarged venter of the archegonium. *S*, stem; *L*, first leaf or cotyledon; *R*, root; *F*, foot.

completely dependent on the sexual stage for its nourishment, remaining attached permanently throughout all its development, by means of the organ called a foot, and it dies after the spores are mature.

561. Now in the ferns we see several striking differences. In the first place, as we have already observed, the spore-bearing phase (sporophyte) of

the plant is the prominent one, and that which characterizes the plant. It also leads an independent existence, and, with the exception of a few cases, does not die after the development of the spores, but lives from year to year and develops successive crops of spores. There is a *distinct advance* here in the *size*, *complexity*, and *permanency* of this phase of the plant.

562. On the other hand the sexual phase of the ferns (gametophyte), while it still is capable of leading an independent existence, is short-lived (with very few exceptions). It is also much smaller than most of the liverworts and

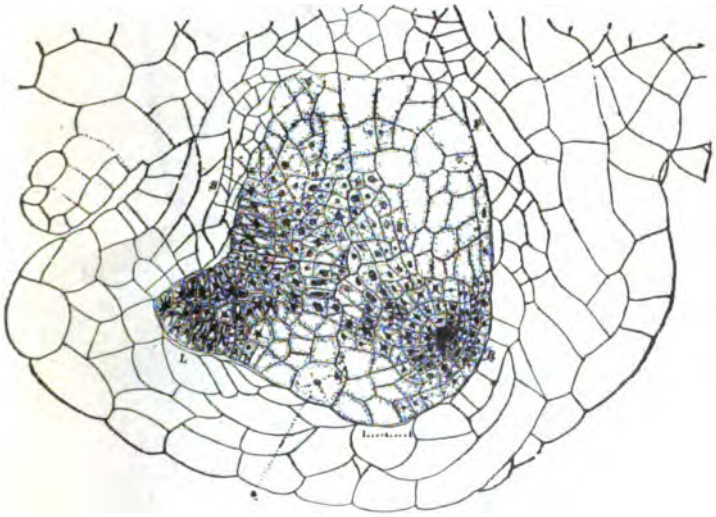

Fig. 313.

Embryo of fern (Adiantum concinnum) still surrounded by the archegonium, which has grown in size, forming the "calyptra." *L*, leaf; *S*, stem; *R*, root; *F*, foot.

mosses, especially as compared with the size of the spore-bearing phase. The gametophyte phase or stage of the plants, then, is decreasing in size and durance as the sporophyte stage is increasing. We shall be interested to see if this holds good of the fern allies, that is of the plants which belong to the same group as the ferns. And as we come later to take up the study of the higher plants we must bear in mind to carry on this comparison, and see if this progression on the one hand of the sporophyte continues, and if the retrogression of the gametophyte continues also.

Fig. 314.
Young plant of Pteris serrulata still attached to prothallium.

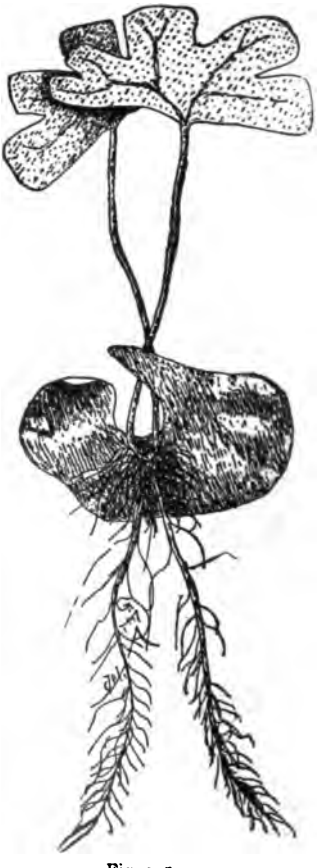

Fig. 315.
Two embryos from one prothallium of Adiantum cuneatum.

CHAPTER XXVIII.

DIMORPHISM OF FERNS.

563. In comparing the different members of the leaf series there are often striking illustrations of the transition from one form to another, as we have noted in the case of the trillium flower. This occurs in many other flowers, and in some, as in the water lily, these transformations are always present, here showing a transition from the petals to the stamens. In the bud scales of many plants, as in the butternut, walnut, currant, etc., there are striking gradations between the form of the simple bud scales and the form of the leaf. Some of the most interesting of these transformations are found in the dimorphic ferns.

564. Dimorphism in the leaves of ferns.—In the common polypody fern, the maidenhair, and in many other ferns, all the leaves are of the same form. That is, there is no difference between the fertile leaf and the sterile leaf. On the other hand, in the case of the Christmas fern we have seen that the fertile leaves are slightly different from the sterile leaves, the former having shorter pinnæ on the upper half of the leaf. The fertile pinnæ are here the shorter ones, and perform but little of the function of carbon conversion. This function is chiefly performed by the sterile leaves and by the sterile portions of the fertile leaves. This is a short step toward the division of labor between the two kinds of leaves, one performing chiefly the labor of carbon conversion, the other chiefly the labor of bearing the fruit.

565. The sensitive fern.—This division of labor is carried to an extreme extent in the case of some ferns. Some of our native

ferns are examples of this interesting relation between the leaves like the common sensitive fern (Onoclea sensibilis) and the ostrich fern (O. struthiopteris) and the cinnamon fern (Osmunda cinnamomea). The sensitive fern is here shown in fig. 316. The sterile leaves are large, broadly expanded, and pinnate, the

Fig. 316.
Sensitive fern; normal condition of vegetative leaves and sporophylls.

pinnæ being quite large. The fertile leaves are shown also in the figure, and at first one would not take them for leaves at all. But if we examine them carefully we see that the general plan of the leaf is the same: the two rows of pinnæ which are here much shorter than in the sterile leaf, and the pinnules, or smaller

divisions of the pinnæ, are inrolled into little spherical masses which lie close on the side of the pinnæ. If we unroll one of these pinnules we find that there are several fruit dots within protected by this roll. In fact when the spores are mature these

Fig. 317.
Sensitive fern; one fertile leaf nearly changed to vegetative leaf.

pinnules open somewhat, so that the spores may be disseminated.

There is very little green color in these fertile leaves, and what green surface there is is very small compared with that of the broad expanse of the sterile leaves. So here there is practically a complete division of labor between these two kinds of

leaves, the general plan of which is the same, and we recognize each as being a leaf.

566. Transformation of the fertile leaves of onoclea to sterile ones.—It is not a very rare thing to find plants of the sensitive fern which show intermediate conditions of the sterile and the fertile leaf. A number of years ago it was thought by some that this represented a different species, but now it is known

Fig. 318.
Sensitive fern, showing one vegetative leaf and two sporophylls completely transformed.

that these intermediate forms are partly transformed fertile leaves. It is a very easy matter in the case of the sensitive fern to produce these transformations by experiment. If one in the spring, when the sterile leaves attain a height of 12 to 16 *cm* (8–10 inches), cuts them away, and again when they have a second time reached the same height, some of the fruiting leaves which develop later will be transformed. A few years ago I cut off the

sterile leaves from quite a large patch of the sensitive fern, once in May, and again in June. In July, when the fertile leaves were appearing above the ground, many of them were changed partly or completely into sterile leaves. In all some thirty plants

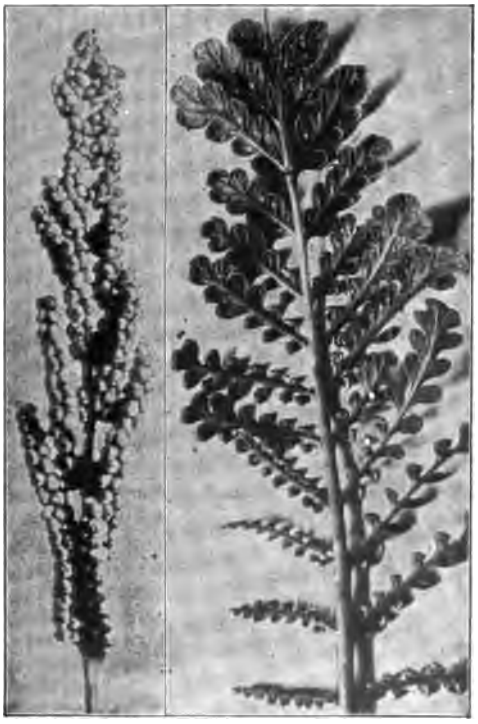

Fig. 310.
Normal and transformed sporophyll of sensitive fern.

showed these transformations, so that every conceivable gradation was obtained between the two kinds of leaves.

567. It is quite interesting to note the form of these changed leaves carefully, to see how this change has affected the pinnæ and the sporangia. We note that the tip of the leaf as well as the tips of all the pinnæ are more expanded than the basal por-

tions of the same. This is due to the fact that the tip of the leaf develops later than the basal portions. At the time the stimulus to the change in the development of the fertile leaves reached them they were partly formed, that is the basal parts of the fertile leaves were more or less developed and fixed and could not change. Those portions of the leaf, however, which were not yet completely formed, under this stimulus, or through correlation of growth, are incited to vegetative growth, and expand more or less completely into vegetative leaves.

568. The sporangia decrease as the fertile leaf expands.—If we now examine the sporangia on the successive pinnæ of a partly transformed leaf we find that in case the lower pinnæ are not changed at all, the sporangia are normal. But as we pass to the pinnæ which show increasing changes, that is those which are more and more expanded, we see that the number of sporangia decrease, and many of them are sterile, that is they bear no spores. Farther up there are only rudiments of sporangia, until on the more expanded pinnæ sporangia are no longer formed, but one may still see traces of the indusium. On some of the changed leaves the only evidences that the leaf began once to form a fertile leaf are the traces of these indusia. In some of these cases the transformed leaf was even larger than the sterile leaf.

569. The ostrich fern.—Similar changes were also produced in the case of the ostrich fern, and in fig. 320 is shown at the left a normal fertile leaf, then one partly changed, and at the right one completely transformed.

570. Dimorphism in tropical ferns.—Very interesting forms of dimorphism are seen in some of the tropical ferns. One of these is often seen growing in plant conservatories, and is known as the staghorn fern (Platycerium alcicorne). This in nature grows attached to the trunks of quite large trees at considerable elevations on the tree, sometimes surrounding the tree with a massive growth. One kind of leaf, which may be either fertile or sterile, is narrow, and branched in a peculiar manner, so that it resembles somewhat the branching of the horn of a stag.

Below these are other leaves which are different in form and sterile. These leaves are broad and hug closely around the roots and bases of the other leaves. Here they serve to catch and

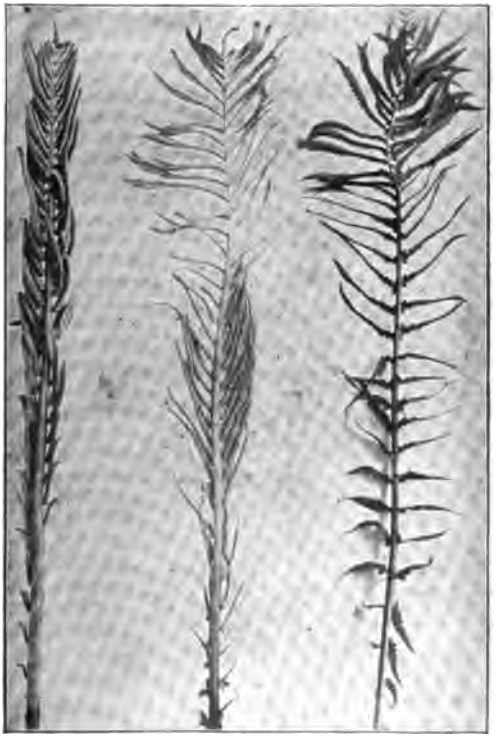

Fig. 320.

Ostrich fern, showing one normal sporophyll, one partly transformed, and one completely transformed.

retain moisture, and they also catch leaves and other vegetable matter which falls from the trees. In this position the leaves decay and then serve as food for the fern.

CHAPTER XXIX.

HORSETAILS.

571. Among the relatives of the ferns are the horsetails, so called because of the supposed resemblance of the branched stems of some of the species to a horse's tail, as one might infer from the plant shown in fig. 325. They do not bear the least resemblance to the ferns which we have been studying. But then relationship in plants does not depend on mere resemblance of outward form, or of the prominent part of the plant.

572. The field equisetum. Fertile shoots.—Fig. 321 represents the common horsetail (Equisetum arvense). It grows in moist sandy or gravelly places, and the fruiting portion of the plant (for this species is dimorphic), that is the portion which bears the spores, appears above the ground early in the spring. It is one of the first things to peep out of the recently frozen ground. This fertile shoot of the plant does not form its growth this early in the spring. Its development takes place under the ground in the autumn, so that with the advent of spring it pushes up without delay. This shoot is from 10 to 20 *cm* high, and at quite regular intervals there are slight enlargements, the nodes of the stem. The cylindrical portions between the nodes are the internodes. If we examine the region of the internodes carefully we note that there are thin membranous scales, more or less triangular in outline, and connected at their bases into a ring around the stem.

Fig. 321. Portion of fertile plant of Equisetum arvense, showing whorls of leaves and the fruiting spike.

Curious as it may seem, these are the leaves of the horsetail. The stem, if we examine it farther, will be seen to possess numerous ridges which extend lengthwise and which alternate with furrows. Farther, the ridges of one node alternate with those of the internode both above and below. Likewise the leaves of one node alternate with those of the nodes both above and below.

573. Sporangia.—The end of this fertile shoot we see possesses a cylindrical to conic enlargement. This is the *fertile spike*, and we note that its surface is marked off into regular areas if the spores have not yet been disseminated. If we dissect off a few of these portions of the fertile spike, and examine one of them with a low magnifying power, it will appear like the fig. 322. We see here that the angular area is a disk-shaped body, with a stalk attached to its inner surface, and with several long sacs projecting from its inner face parallel with the stalk and surrounding the same. These elongated sacs are the *sporangia*, and the disk which bears them, together with the stalk which attaches it to the stem axis, is the *sporophyll*, and thus belongs to the leaf series. These sporophylls are borne in close whorls on the axis.

Fig. 322. Peltate sporophyll of equisetum (side view) showing sporangia on under side.

574. Spores.—When the spores are ripe the tissue of the sporangium becomes dry, and it cracks open and the spores fall out. If we look at fig. 323 we see that the spore is covered with a very singular coil which lies close to the wall. When the spore dries this uncoils and thus rolls the spore about. Merely breathing upon these spores is sufficient to make them perform very curious evolutions by the twisting of these four coils which are attached to one place of the wall. They are formed by the splitting up of an outer wall of the spore.

575. Sterile shoot of the common horsetail.—When the spores are ripe they are soon scattered, and then the fertile shoot dies down. Soon afterward, or even while some of the fertile shoots are still in good condition, sterile shoots of the

plant begin to appear above the ground. One of these is shown in fig. 325. This has a much more slender stem and is pro-

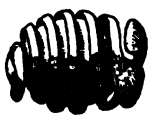

Fig. 323.
Spore of equisetum with elaters coiled up.

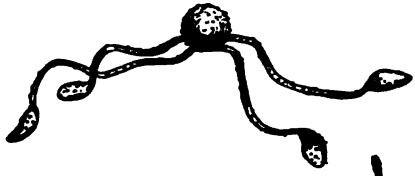

Fig. 324.
Spore of equisetum with elaters uncoiled.

vided with numerous branches. If we examine the stem of this shoot, and of the branches, we see that the same kind of leaves are present and that the markings on the stem are similar. Since the leaves of the horsetail are membranous and not green, the stem is green in color, and this performs the function of photosynthesis. These green shoots live for a great part of the season, building up material which is carried down into the underground stems, where it goes to supply the forming fertile shoots in the fall. On digging up some of these plants we see that the underground stems are often of great extent, and that both fertile and sterile shoots are attached to one and the same.

576. The scouring rush, or shave grass. —Another common species of horsetail in the Northern States grows on wet banks, or in sandy soil which contains moisture along railroad embankments. It is the scouring rush (E. hyemale), so called because it was once used for polishing purposes. This plant like all the species of the horsetails has

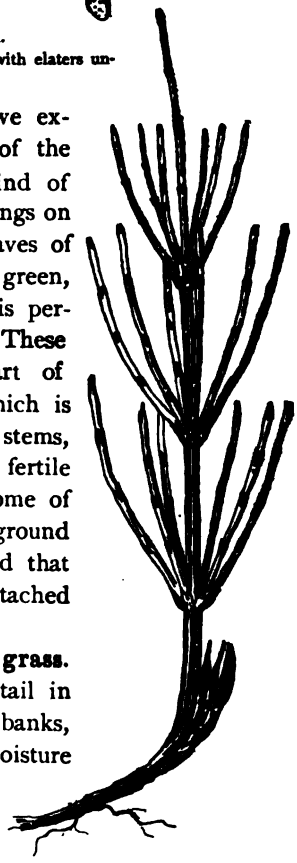

Fig. 325.
Sterile plant of horsetail (Equisetum arvensis).

underground stems. But unlike the common horsetail, there is but one kind of aerial shoot, which is green in color and fertile. The shoots range as high as one meter or more, and are quite stout. The new shoots which come up for the year are unbranched, and bear the fertile spike at the apex. When the spores are ripe the apex of the shoot dies, and the next season small branches may form from a number of the nodes.

577. Gametophyte of equisetum.—The spores of equisetum have chlorophyll when they are mature, and they are capable of germinating as soon as mature. The spores are all of the same kind as regards size, just as we found in the case of the ferns. But they develop prothallia of different sizes, according to the amount of nutriment which they obtain. Those which obtain but little nutriment are smaller and develop only antheridia, while those which obtain more nutriment become larger, more or less branched, and develop archegonia. This character of an independent prothallium (gametophyte) with the characteristic sexual organs, and the also independent sporophyte, with spores, shows the relationship of the horsetails with the ferns. We thus see that these characters of the reproductive organs, and the phases and fruiting of the plant, are more essential in determining relationships of plants than the mere outward appearances.

CHAPTER XXX.

CLUB MOSSES.

578. What are called the "club mosses" make up another group of interesting plants which rank as allies of the ferns. They are not of course true mosses, but the general habit of some of the smaller species, and especially the form and size of the leaves, suggest a resemblance to the larger of the moss plants.

579. The clavate lycopodium.—Here is one of the club mosses (fig. 326) which has a wide distribution and which is well entitled to hold the name of club because of the form of the upright club-shaped branches. As will be seen from the illustration, it has a prostrate stem. This stem runs for considerable distances on the surface of the ground, often partly buried in the leaves, and sometimes even buried beneath the soil. The leaves are quite small, are flattened-awl-shaped, and stand thickly over the stem, arranged in a spiral manner, which is the usual arrangement of the leaves of the club mosses. Here and there are upright branches which are forked several times. The end of one or more of these branches becomes produced into a slender upright stem which is nearly leafless, the leaves being reduced to mere scales. The end of this leafless branch then terminates in one or several cylindrical heads which form the club.

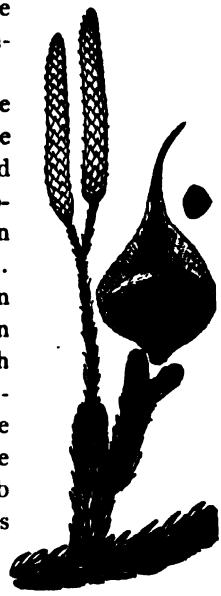

Fig. 326.
Lycopodium clavatum, branch bearing two fruiting spikes; at right sporophyll with open sporangium; single spore near it.

580. Fruiting spike of Lycopodium clavatum.—This club is the fruiting spike or head (sometimes termed a *strobilus*). Here the leaves are larger again and broader, but still not so large as the leaves on the creeping shoots, and they are paler. If we bend down some of the leaves, or tear off a few, we see that in the axil of the leaf, where it joins the stem, there is a somewhat rounded, kidney-shaped body. This is the spore-case or sporangium, as we can see by an examination of its contents. There is but a single spore-case for each of the fertile leaves (sporophyll). When it is mature, it opens by a crosswise slit as seen in fig. 326. When we consider the number of spore-cases in one of these club-shaped fruit bodies we see that the number of spores developed in a large plant is immense. In mass the spores make a very fine, soft powder, which is used for some kinds of pyrotechnic material, and for various toilet purposes.

Fig. 327.

Lycopodium lucidulum, bulbils in axils of leaves near the top, sporangia in axils of leaves below them. At right is a bulbil enlarged.

581. Lycopodium lucidulum.—Another common species is figured at 327. This is Lycopodium lucidulum. The habit of the plant is quite different. It grows in damp ravines, woods, and moors. The older parts of the stem are prostrate, while the branches are more or less ascending. It branches in a forked manner. The leaves are larger than in the former species, and they are all of the same size, there being no appreciable difference between the sterile and fertile ones. The characteristic club is not present here, but the spore-cases occupy certain regions of the stem, as shown at 327. In a single season one region of the stem may bear spore-cases, and then a sterile portion of the same stem is developed, which later bears another series of spore-cases higher up.

582. Bulbils on Lycopodium lucidulum.—There is one curious way in which this club moss multiplies. One may see frequently among the upper leaves small wedge-shaped or heart-shaped green bodies but little larger than the ordinary leaves. These are little

buds which contain rudimentary shoot and root and several thick green leaves. When they fall to the ground they grow into new lycopodium plants, just as the bulbils of cystopteris do which were described in the chapter on ferns.

583. Note.—The prothallia of the species of lycopodium which have been studied are singular objects. In L. cernuum a cylindrical body sunk in the earth is formed, and from the upper surface there are green lobes. In L. phlegmaria and some others slender branched, colorless bodies are formed which according to Treub grow as a saphrophyte in decayed bark of trees. Many of the prothallia examined have a fungus growing in their tissue which is supposed to play some part in the nutrition of the prothallium.

The little club mosses (selaginella).

584. Closely related to the club mosses are the selaginellas. These plants resemble closely the general habit of the club mosses, but are generally smaller and the leaves more delicate. Some species are grown in conservatories for ornament, the leaves of

Fig. 328. Selaginella with three fruiting spikes. (Selaginella apus.)

Fig. 329. Fruiting spike showing large and small sporangia.

Fig. 330. Large sporangium.

Fig. 331. Small sporangium.

such usually having a beautiful metallic lustre. The leaves of some are arranged as in lycopodium, but many species have the leaves in four to six rows. Fig. 328 represents a part of a selaginella plant (S. apus). The fruiting spike possesses similar leaves, but they are shorter, and their arrangement gives to the spike a four-sided appearance.

585. Sporangia.—On examining the fruiting spike, we find as in lycopodium that there is but a single sporangium in the axil of a fertile leaf. But we see that they are of two different kinds, small ones in the axils of the upper leaves, and large ones in the axils of a few of the lower leaves of the spike. The *microspores* are borne in the smaller spore-cases and the *macrospores* in the larger ones. Figures 329–331 give the details. There are many microspores in a single small spore-case, but 3–4 macrospores in a large spore-case.

586. Male prothallia.—The prothallia of selaginella are much reduced structures. The microspores when mature are already divided into two cells. When they grow into the mature prothallium a few more cells are formed, and some of the inner ones form the spermatozoids, as seen in fig. 332. Here we see that

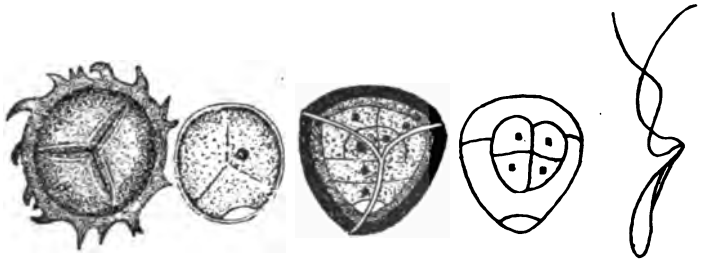

Fig. 332.

Details of microspore and male prothallium of selaginella; 1st, microspore; 2d, wall removed to show small prothallial cell below; 3d, mature male prothallium still within the wall; 4th, small cell below is the prothallial cell, the remainder is antheridium with wall and four sperm cells within; 5th spermatozoid. After Beliaieff and Pfeffer.

the antheridium itself is larger than the prothallia. Only antheridia are developed on the prothallia formed from the microspores, and for this reason the prothallia are called *male prothallia*. In fact a male prothallium of selaginella is nearly all antheridium, so reduced has the gametophyte become here.

587. Female prothallia.—The female prothallia are developed from the macrospores. The macrospores when mature have a rough, thick, hard wall. The female prothallium begins to develop inside of the macrospore before it leaves the sporangium. The protoplasm is richer near the wall of the spore and at the

upper end. Here the nucleus divides a great many times, and finally cell walls are formed, so that a tissue of considerable extent is formed inside the wall of the spore, which is very different from what takes place in the ferns we have studied. As the prothallium matures the spore is cracked at the point where the three angles meet, as shown in fig. 334. The archegonia are developed in this exposed surface, and several can be seen in the illustration.

588. Embyro.—After fertilization the egg divides in such a way that a long cell called a suspensor is cut off from the upper side,

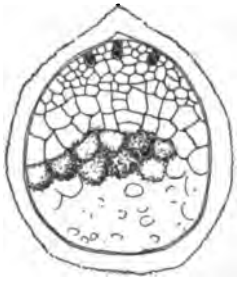

Fig. 333.
Section of mature macrospore of selaginella, showing female prothallium and archegonia. After Pfeffer.

Fig. 334.
Mature female prothallium of selaginella, just bursting open the wall of macrospore, exposing archegonia. After Pfeffer.

Fig. 335.
Seedling of selaginella still attached to the macrospore. After Campbell.

which elongates and pushes the developing embyro down into the center of the spore, or what is now the female prothallium. Here it derives nourishment from the tissues of the prothallium, and eventually the root and stem emerge, while a process called the "foot" is still attached to the prothallium. When the root takes hold on the soil the embyro becomes free.

Fig. 336.
Isoetes, mature plant, sporophyte stage.

CHAPTER XXXI.

QUILLWORTS (ISOETES).

589. The quillworts, as they are popularly called, are very curious plants. They grow in wet marshy places. They receive their name from the supposed resemblance of the leaf to a quill. Fig. 336 represents one of these quillworts (Isoetes engelmannii). The leaves are the prominent part of the plant, and they are about all that can be seen except the roots, without removing the leaves. Each leaf, it will be seen, is long and needle-like, except the basal part, which is expanded, not very unlike, in outline, a scale of an onion. These expanded basal portions of the leaves closely overlap each other, and the very short stem is completely covered at all times. Fig. 338 is from a longitudinal section of a quillwort. It shows the form of the leaves from this view (side view), and also the general outline of the short stem, which is triangular. The stem is therefore a very short object.

590. Sporangia of isoetes.—If we pull off some of the leaves of the plant we see that they are somewhat spoon-shaped as in fig. 337. In the inner surface of the expanded base we note a circular depression which seems to be of a different text-

Fig. 337.
Base of leaf of isoetes, showing sporangium with macrospores. (Isoetes engelmannii.)

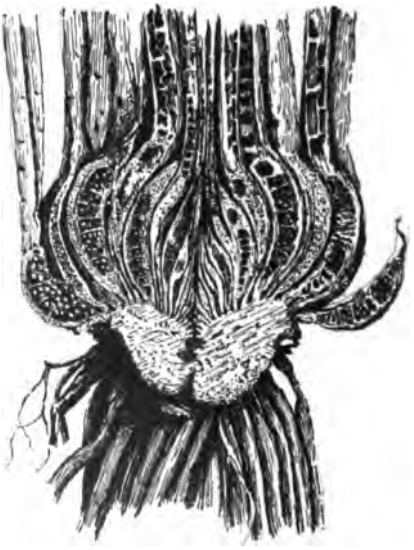

Fig. 338.
Section of plant of Isoetes engelmanni, showing cup-shaped stem, and longitudinal sections of the sporangia in the thickened bases of the leaves.

ure from the other portions of the leaf. This is a *sporangium*. Beside the spores on the inside of the sporangium, there are strands of sterile tissue which extend across the cavity. This is peculiar to isoetes of all the members of the class of plants to which the ferns belong, but it will be remembered that sterile strands of tissue are found in some of the liverworts in the form of elaters.

591. The spores of isoetes are of two kinds, small ones (microspores) and large ones (macrospores), so that in this respect it agrees with selaginella, though it is so very different in other respects. When one kind of spore is borne in a sporan-

gium usually all in that sporangium are of the same kind, so that certain sporangia bear microspores, and others bear macrospores. But it is not uncommon to find both kinds in the same sporangium. When a sporangium bears only microspores the number is much greater than when one bears only macrospores.

592. If we examine some of the microspores of isoetes we see that they are shaped like the quarters of an apple, that is they are of the bilateral type as seen in some of the ferns (asplenium).

593. Male prothallia.—In isoetes, as in selaginella, the microspores develop only male prothallia, and these are very rudimentary, one division of the spore having taken place before the spore is mature, just as in selaginella.

594. Female prothallia.—These are developed from the macrospores. The latter are of the tetrahedral type. The development of the female prothallium takes place in much the same way as in selaginella, the entire prothallium being enclosed in the macrospore, though the cell divisions take place after it has left the sporangium. When the archegonia begin to develop the macrospore cracks at the three angles and the surface bearing the archegonia projects slightly as in selaginella. Absorbing organs in the form of rhizoids are very rarely formed.

595. Embryo.—The embryo lies well immersed in the tissue of the prothallium, though there is no suspensor developed as in selaginella.

CHAPTER XXXII.

COMPARISON OF FERNS AND THEIR RELATIVES.

596. Comparison of selaginella and isoetes with the ferns.—On comparing selaginella and isoetes with the ferns. we see that the sporophyte is, as in the ferns, the prominent part of the plant. It possesses root, stem, and leaves. While these plants are not so large in size as some of the ferns, still we see that there has been a great advance in the sporophyte of selaginella and isoetes upon what exists in the ferns. There is a division of labor between the sporophylls, in which some of them bear microsporangia with microspores, and some bear macrosporangia with only macrospores. In the ferns and horsetails there is only one kind of sporophyll, sporangium, and spore in a species. By this division of labor, or differentiation, between the sporophylls, one kind of spore, the microspore, is compelled to form a male prothallium, while the other kind of spore, the macrospore, is compelled to form a female prothallium. This represents a progression of the sporophyte of a very important nature.

597. On comparing the gametophyte of selaginella and isoetes with that of the ferns, we see that there has been a still farther retrogression in size from that which we found in the independent and large gametophyte of the liverworts and mosses. In the ferns, while it is reduced, it still forms rhizoids, and leads an independent life, absorbing its own nutrient materials, and assimilating carbon. In selaginella and isoetes the gametophyte does not escape from the spore, nor does it form absorbing organs, nor develop assimilative tissue. The reduced prothallium develops at the expense of food stored by the sporophyte while the spore is developing. Thus, while the gametophyte is separate from the sporophyte in selaginella and isoetes, it is really dependent on it for support or nourishment.

598. The important general characters possessed by the ferns and their so-called allies, as we have found, are as follows: The spore-bearing part, which is the fern plant, leads an independent existence from the prothallium, and forms root, stem, and leaves. The spores are borne in sporangia on the leaves. The prothallium also leads an independent existence, though in isoetes and selaginella it has become almost entirely dependent on the sporo-

Classification of the Pteridophytes.

Of the living pteridophytes four classes may be recognized.

CLASS FILICINEÆ.*

This class includes the ferns. Four orders may be recognized.

600. Order Ophioglossales. (One Family, Ophioglossaceæ).—This order includes the grapeferns (Botrychium), so called because of the large botryoid cluster of sporangia, resembling roughly a cluster of grapes; and the adder-tongue (Ophioglossum), the sporangia being embedded in a long tongue-like outgrowth from the green leaf. Botrychium and Ophioglossum are widely distributed. The roots are fleshy, nearly destitute of root hairs, and contain an endophytic fungus, so that the roots are mycorhiza. The gametophyte is subterranean, and devoid of chlorophyll. In Botrychium virginianum, an endophytic fungus has been found in the prothallium. Another genus (Helminthostachys) with one species is limited to the East Indies.

601. Order Marattiales (One Family, Marattiaceæ).—These are tropical ferns, with only four or five living genera (Marattia, Danæa, etc.). They resemble the typical ferns, but the sporangia are usually united, several forming a compound sporangium, or *synangium*.

The Ophioglossales and Marattiales are known as eusporangiate ferns, while the following order includes the leptosporangiate ferns.

602. Order Filicales.—This order includes the typical ferns. Eight families are recognized.

Family Osmundaceæ.—Three genera are known in this family. Osmunda has a number of species, three of which are found in the Eastern United States; the cinnamon-fern (O. cinnamomea), the royal fern (O. regalis), and Clayton's fern (O. claytoniana). No species of this family are found on the Pacific coast.

Family Gleicheniaceæ.—These ferns are found chiefly in the tropics, and in the mountain regions of the temperate zones of South America. There are two genera, Gleichenia containing all but one of the known species.

Family Matoniaceæ.— One genus, Matonia, in the Malayan region.

Family Schizæaceæ.—These are chiefly tropical, but two species are found in eastern North America, Schizæa pusilla and Lygodium palmatum, the latter a climbing fern.

Family Hymenophyllaceæ.—These are known as the filmy ferns because of their thin, delicate leaves. They grow only in damp or wet regions, mostly in the tropics, but a few species occur in the southern United States.

Family Cyatheaceæ.—These are known as the tree-ferns, because of the

* As class Filicales in Engler and Prantl.

large size which many of them attain. They occur chiefly in tropical mountainous regions, many of them palm-like and imposing because of the large trunks and leaves. Dicksonia, Cyathea, Cibotium, Alsophila, are some of the most conspicuous genera.

Family Parkeriaceæ.—There is a single species in this family (Ceratopteris thalictroides), abundant in the tropics and extending into Florida. It is aquatic.

Family Polypodiaceæ.—This family includes the larger number of living ferns and many genera and species are found in North America. Examples, Polypodium, Pteridium (=Pteris), Adiantum, etc.

603. Order Hydropterales (or Salviniales).—The members of this order are peculiar, aquatic ferns, some floating on the water (Azolla, Salvinia), while others are anchored to the soil by roots (Marsilia, Pilularia). They are known as water ferns. The sporangia are of two kinds, one containing large spores (macrospores) and the other small spores (microspores). They are therefore heterosporous ferns.

Family Salviniaceæ.—There are two genera, Salvinia and Azolla.

Family Marsiliaceæ.—Two genera, Marsilia and Pilularia. In this family the sporangia are enclosed in a sporocarp, which forms a pod-like structure.

CLASS EQUISETINEÆ.*

604. Order Equisetales.—The single order contains a single family, Equisetaceæ, among the living forms, and but a single genus, Equisetum. There are about twenty-four species, with fourteen in the United States (see Chapter XXIX).

CLASS LYCOPODIINEÆ.†

605. Order Lycopodiales.—The first two families of this order include the homosporous Lycopodiineæ, while the Selaginellaceæ are heterosporous.

Family Lycopodiaceæ.—There are two genera. Lycopodium (club moss) includes many species, most of them tropical, but a number in temperate and subarctic regions. The gametophyte of many species is tuberous, lacks chlorophyll, and in some there lives an endophytic fungus. Phylloglossum with one species is found in Australia.

Family Psilotaceæ.—There are two genera. Psilotum chiefly in the tropics has one species (P. triquetrum) in the region of Florida.

Family Selaginellaceæ.—These include the little club mosses, with one genus, Selaginella (see Chapter XXX).

CLASS ISOETINEÆ.

606. Order Isoetales, with one family Isoetaceæ and one genus Isoetes (see Chapter XXXI). There are about fifty species, with about sixteen in the United States.

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* As class Equisetales in Engler and Prantl.

† As class Lycopodiales in Engler and Prantl.

CHAPTER XXXIII.

GYMNOSPERMS.

The white pine.

607. General aspect of the white pine.—The white pine (Pinus strobus) is found in the Eastern United States. In favorable situations in the forest it reaches a height of about 50 meters (about 160 feet), and the trunk a diameter of over 1 meter. In well-formed trees the trunk is straight and towering; the branches where the sunlight has access and the trees are not crowded, or are young, reaching out in graceful arms, form a pyramidal outline to the tree. In old and dense forests the lower branches, because of lack of sunlight, have died away, leaving tall, bare trunks for a considerable height.

608. The long shoots of the pine.—The branches are of two kinds. Those which we readily recognize are the long branches, so called because the growth in length each year is considerable. The terminal bud of the long branches, as well as of the main stem, continues each year the growth of the main branch or shoot; while the lateral long branches arise each year from buds which are crowded close together around the base of the terminal bud. The lateral long branches of each year thus appear to be in a whorl. The distance between each false whorl of branches, then, represents one year's growth in length of the main stem or long branch.

609. The dwarf shoots of the pine.—The dwarf branches are all lateral on the long branches, or shoots. They are scattered over the year's growth, and each bears a cluster of five long, needle-shaped, green leaves, which remain on the tree for several years. At the base of the green leaves are a number of chaff-like scales, the previous bud scales. While the dwarf branches thus bear green leaves, and scales, the long branches bear only thin scale-like leaves which are not green.

610. Spore-bearing leaves of the pine.—The two kinds of spore-bearing leaves of the pine, and their close relatives, are so different from anything which we have yet studied, and are so unlike the green leaves of the pine, that we would scarcely recognize them as belonging to this category. Indeed there is great uncertainty regarding their origin.

611. Male cones, or male flowers.—The male cones are borne in clusters as shown in fig. 339. Each compact, nearly cylindri-

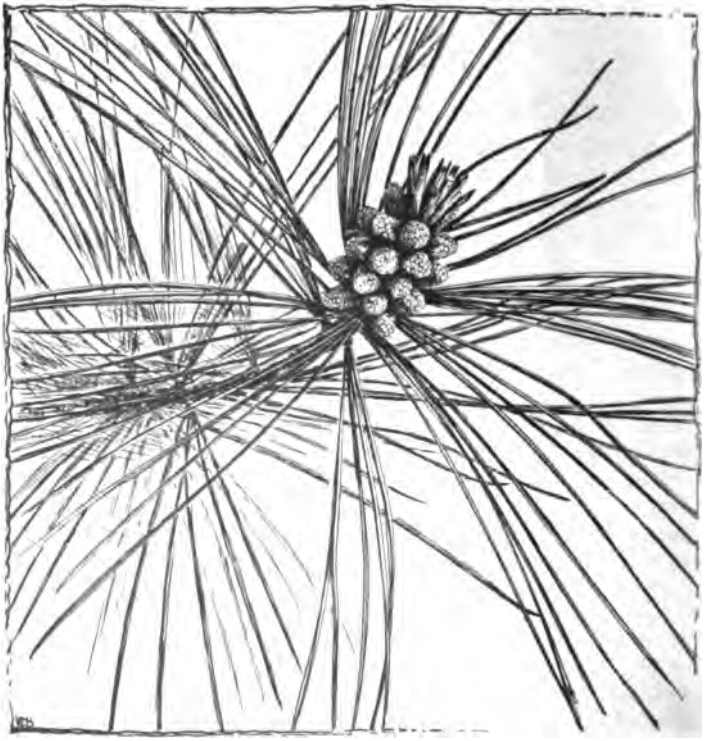


Fig. 339.
Spray of white pine showing cluster of male cones just before the scattering of the pollen.

cal, or conical mass is termed a cone, or flower, and each arises in place of a long lateral branch. One of these cones is shown

considerably enlarged in fig. 340. The central axis of each cone is a lateral branch, and belongs to the stem series. The stem axis of the cone can be seen in fig. 341. It is completely covered by stout, thick, scale-like outgrowths. These scales are obovate in outline, and at the inner angle of the upper end

Fig. 340. Staminate cone of white pine, with bud scales removed on one side.

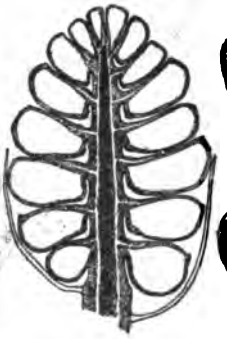


Fig. 341. Section of staminate cone, showing sporangia.

Fig. 342. Two sporophylls removed, showing opening of sporangia.

there are several rough, short spines. They are attached by their inner lower angle, which forms a short stalk or petiole, and continues through the inner face of the scale as a "mid-rib." What corresponds to the lamina of the scale-like leaf bulges out on each side below and makes the bulk of the scale. These prominences on the under side are the sporangia (microsporangia). There are thus two sporangia on a sporophyll (microsporophyll). When the spores (microspores), which here are usually called pollen grains, are mature each sporangium, or anther locule, splits down the middle as shown in fig. 342, and the spores are set free.

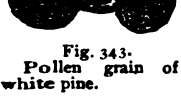


Fig. 343. Pollen grain of white pine.

612. Microspores of the pine, or pollen grains.—A mature pollen grain of the pine is shown in fig. 343. It is a queer-looking object, possessing on two sides an air sac, formed by the upheaval of the outer coat of the spore at these two points.

When the pollen is mature, the moisture dries out of the scale (or stamen, as it is often called here) while it ripens. When a limb, bearing a cluster of male cones, is jarred by the hand, or by currents of air, the split suddenly opens, and a cloud of pollen bursts out from the numerous anther locules. The pollen is thus borne on the wind and some of it falls on the female flowers.

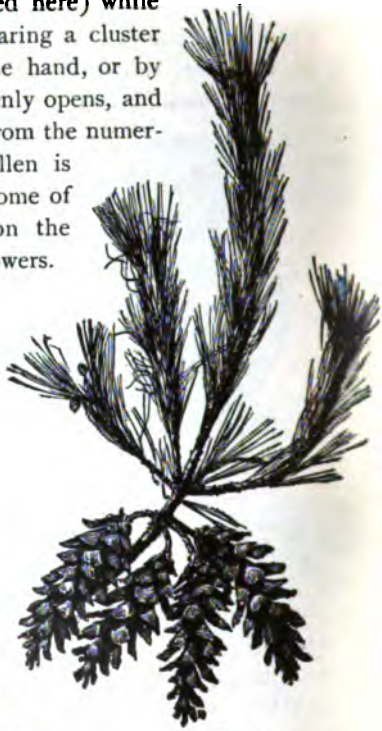


Fig. 344.
White pine, branch with cluster of mature cones shedding the seed. A few young cones four months old are shown on branch at the left. Drawn from photograph.

Fig. 345.
Mature cone of white pine at time of scattering of the seed, nearly natural size.

613. Form of the mature female cone.—A cluster of the white-pine cones is shown in fig. 344. These are mature, and the scales have spread as they do when mature and becoming dry, in order that the seeds may be set at liberty. The general out-

line of the cone is lanceolate, or long oval, and somewhat curved. It measures about 10–15*cm* long. If we remove one

Fig. 346. Sterile scale. Seeds undeveloped.

Fig. 347. Scale with well-developed seeds.

Fig. 348. Seeds have split off from scale.

Fig. 349. Back of scale with small cover scale.

Fig. 350. Winged seed free from scale.

Figs. 346–350.—White pine showing details of mature scales and seed.

of the scales, just as they are beginning to spread, or before the seeds have scattered, we shall find the seeds attached to the upper surface at the lower end. There are two seeds on each scale, one at each lower angle. They are ovate in outline, and shaped somewhat like a biconvex lens. At this time the seeds easily fall away, and may be freed by jarring the cone. As the seed is detached from the scale a strip of tissue from the latter is peeled off. This forms a "wing" for the seed. It is attached to one end and is shaped something like a knife blade. On the back of the scale is a small appendage known as the cover scale.

Fig. 351. Female cones of the pine at time of pollination, about natural size.

614. Formation of the female pine cone.—The female flowers begin their development rather late in the spring of the year. They are formed from terminal buds of the higher branches of the tree. In this way the cone may terminate the main shoot of a branch, or of the lateral shoots in a whorl. After growth has proceeded for some time in the spring, the terminal portion begins to assume the appearance of a young female cone or

flower. These young female cones, at about the time that the pollen is escaping from the anthers, are long ovate, measuring about 6–10*mm* long. They stand upright as shown in fig. 351.

615. Form of a "scale" of the female flower.—If we remove one of the scales from the cone at this stage we can better study it in detail. It is flattened, and oval in outline, with a stout "rib," if it may be so called, running through the middle line and terminating in a point. The scale is in two parts as shown in fig. 354, which is a view of the under side. The small "outgrowth" which appears as an appendage is the cover scale, for while it is smaller in the pine than the other portion, in some of the relatives of the pine it is larger than its mate, and being on the outside, covers it. (The inner scale is sometimes called the ovuliferous scale, because it bears the ovules.)

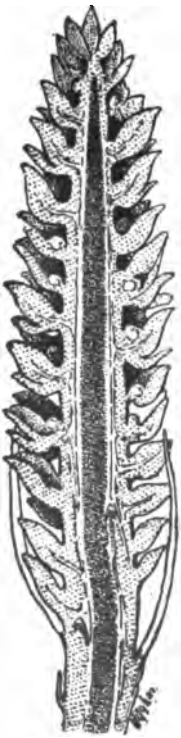


Fig. 352.
Section of female cone of white pine, showing young ovules (macrosporangia) at base of the ovuliferous scales.

616. Ovules, or macrosporangia, of the pine.—At each of the lower angles of the

Fig. 353.
Scale of white pine with the two ovules at base of ovuliferous scale.

Fig. 354.
Scale of white pine seen from the outside, showing the cover scale.

scale is a curious oval body with two curved, forceps-like processes at the lower and smaller end. These are the macrosporangia, or, as they are called in the higher plants, the ovules. These ovules, as we see, are in the positions of the seeds on the

mature cones. In fact the wall of the ovule forms the outer coat of the seed, as we will later see.

617. Pollination.—At the time when the pollen is mature the female cones are still erect on the branches, and the scales, which during the earlier stages of growth were closely pressed against one another around the axis, are now spread apart. As the clouds of pollen burst from the clusters of the male cones, some of it is wafted by the wind to the female cones. It is here caught in the open scales, and rolls down to their bases, where some of it falls between these forceps-like processes at the lower end of the ovule. At this time the ovule has exuded a drop of a sticky fluid in this depression between the curved processes at its lower end. The pollen sticks to this, and later, as this viscid substance dries up, it pulls the pollen close up in the depression against the lower

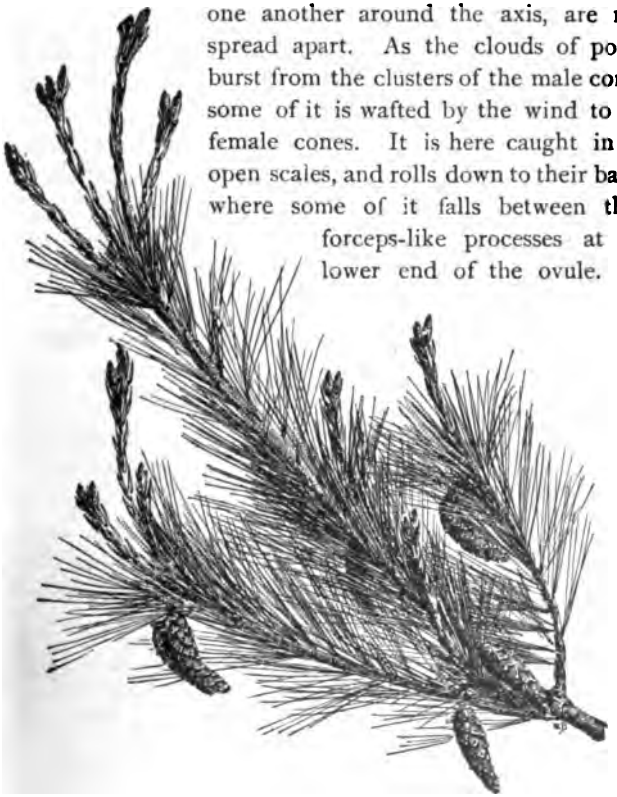


Fig. 355.

Branch of white pine showing young female cones at time of pollination on the ends of the branches, and one-year-old cones below, near the time of fertilization.

end of the ovule. This depression is thus known as the *pollen chamber*.

618. Now the open scales on the young female cone close up again so tightly that water from rains is excluded. What is also very curious, the cones, which up to this time have been standing erect, so that the open scale could catch the pollen, now turn so that they hang downward. This more certainly excludes the rains, since the overlapping of the scales forms a shingled surface. Quantities of resin are also formed in the scales, which exudes and makes the cone practically impervious to water.

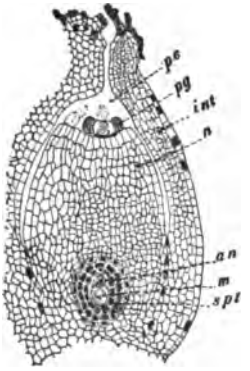


Fig. 356.

Macrosporangium of pine (ovule). *int*, integument; *n*, nucellus; *m*, macrospore; *pc*, pollen chamber; *pg*, pollen grain; *an*, axile row; *spt*, spongy tissue. (After Ferguson.)

619. The female cone now slowly grows during the summer and autumn, increasing but little in size during this time. During the winter it rests, that is, ceases to grow. With the coming of spring, growth commences again and at an accelerated rate. The increase in size is more rapid. The cone reaches maturity in September. We thus see that nearly eighteen months elapse from the beginning of the female flower to the maturity of the cone, and about fifteen months from the time that pollination takes place.

620. Female prothallium of the pine.—To study this we must make careful longitudinal sections through the ovule (better made with the aid of a microtome). Such a section is shown in fig. 358. The outer layer of tissue, which at the upper end (point where the scale is attached to the axis of the cone) stands free, is the ovular coat, or *integument*. Within this integument, near the upper end, there is a cone-shaped mass of tissue. This mass of tissue is the *nucellus*, or the *macrosporangium* proper. In the lower part of the nucellus in fig. 356 can be seen a rounded mass of "spongy tissue" (*spt*), which is a special nourishing tissue of the nucellus, or sporangium, around the macrospore. Within this can be seen an axile row of three cells (*an* : *m*). The lowest one, which is larger than the other two, is the *macrospore*. Sometimes there are four of these cells in the axile row. This axile row of three or four cells is formed by the two successive

divisions of a mother cell in the nucellus. So it would appear that these three or four cells are all spores.

Only one of them, however, the lower one, develops; the others are disorganized and disappear. The nucleus of the macrospore now divides several times to form several free nuclei in the now enlarging cavity, much as the nucleus of the macrospore in Selaginella and Isoetes divides within the spore. The development thus far takes place during the first summer, and now with the approach of winter the very young female prothallium goes into rest about the stage shown in fig. 358. The conical portion of the nucellus which lies above is the nucellar cap.

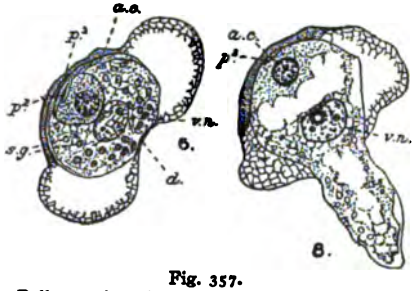


Fig. 357.

Pollen grains of pine. One of them germinating. p^1 and p^2, the two disintegrated prothallial cells, = sterile part of male gametophyte; *a.c.*, central cell of antheridium; *v.n.*, vegetative nucleus or tube nucleus of the single-wall cell of antheridium; *s.g.*, starch grains. (After Ferguson.)

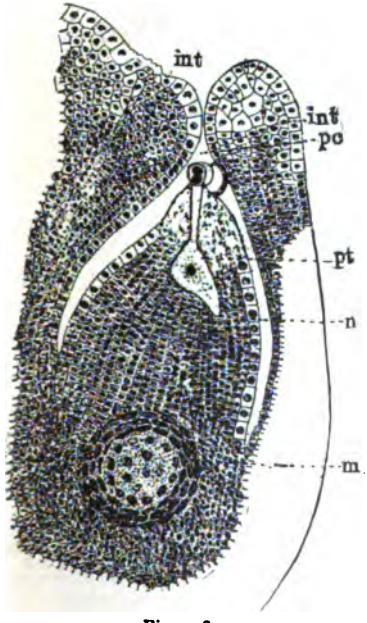


Fig. 358.

Section of ovule of white pine. *int*, integument; *pc*, pollen chamber; *pt*, pollen tube; *n*, nucleus; *m*, macrospore cavity.

621. Male prothallia.—By the time the pollen is mature the male prothallium is already partly formed. In fig. 343 we can see two well-formed cells. Two other cells are formed earlier, but they become so flattened that it is difficult to make them out when the pollen grain is mature. These are shown in fig. 357, p^1 and p^2, and they are the only sterile cells of the male prothallium in the pines. The large cell is the antheridium wall, its nucleus *v.n.* in fig. 357. The smaller cell, *a.c.*, is the central cell of the antheridium. During the summer and autumn the male prothallium makes some farther growth, but this is slow. The larger cell, called the vegetative cell or tube cell, which is in reality the wall of the antheridium, elon-

gates by the formation of a tube, forming a sac, known as the pollen tube It is either simple or branched. It grows down into the tissue of the nucellus, and at a stage represented in fig. 358, winter overtakes it and it rests. At this time the central cell has divided into two cells, and the vegetative nucleus is in the pollen tube.

622. The endosperm.—In the following spring growth of all these parts

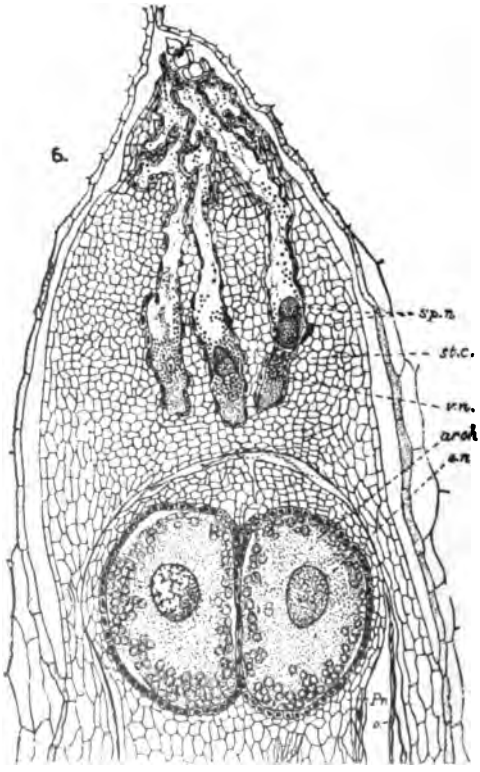


Fig. 359.

Section of nucellus and endosperm of white pine. The inner layer of cells of the integument shown just outside of nucellus; *arch*, archegonium; *en*, egg nucleus. In the nucellar cap are shown three pollen tubes. *vn*, vegetative nucleus or tube nucleus; *stc*, stalk cell; *spn*, sperm nuclei, the larger one in advance is the one which unites with the egg nucleus. The archegonia are in the endosperm or female gametophyte. (After Ferguson.)

continues. The nuclei in the macrospore divide to form more, and eventually cell walls are formed between them making a distinct tissue, known

as the *endosperm*. This endosperm continues to grow until a large part of the nucellus is consumed for food.

623. Female prothallium and archegonia.—The endosperm is the female prothallium. This is very evident from the fact that several archegonia are developed in it usually on the side toward the pollen chamber. The archegonia are sexual organs, and since the sexual organs are developed on the gametophyte, therefore, the endosperm is the female gametophyte, or prothallium. In fig. 359 are represented two archegonia in the endosperm and the pollen tubes are growing down through the nucellus. The archegonia are quite large, the wall is a sheath or jacket of cells which encloses the very large egg which has a large nucleus in the center.

624. Pollen tube and sperm cells.—While the endosperm (female prothallium) and archegonia are developing the pollen tube continues its growth down through the nucellar cap, as shown in fig. 359. At the same time the two cells which were formed in the pollen grain (antheridium) from the central cell move down into the tube. One of these is the "generative" cell, or "body" cell, and the other is called the stalk cell, though it is more properly a sterile half of the central cell. The nucleus of the generative cell, about the time the archegonium is mature, divides to form two nuclei, which are the sperm nuclei, and the one in advance is the larger, though it is much smaller than the egg nucleus.

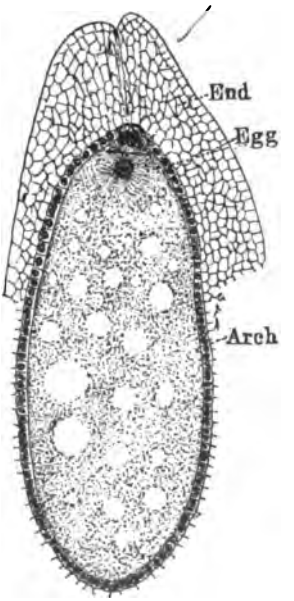


Fig. 360.

Last division of the egg in the white pine cutting off the ventral canal cell at the apex of the archegonium. *End*, endosperm; *Arch*, archegonium.

625. Fertilization.—Very soon after the archegonia are mature (early in June in the northern United States) the pollen tube grows through into the archegonium and empties the two sperm nuclei, the vegetative nucleus and the stalk cell, into the protoplasm of the large egg. The larger of the two sperm nuclei at once comes in contact with the very large egg nucleus and sinks down into a depression of the same, as shown in fig. 361. These two nuclei, in the pines, do not fuse into a resting nucleus, but at once organize the nuclear figure for the first division of the embryo. Two nuclei are thus formed, and these divide to form four nuclei which sink to the bottom of the archegonium and there organ-

ize the embryo which pushes its way into the endosperm from which it derives its food (fig. 362).

626. Homology of the parts of the female cone.—Opinions are divided as to the homology of the parts of the female cone of the pine. Some consider the entire cone to be homologous with a flower of the angiosperms. The

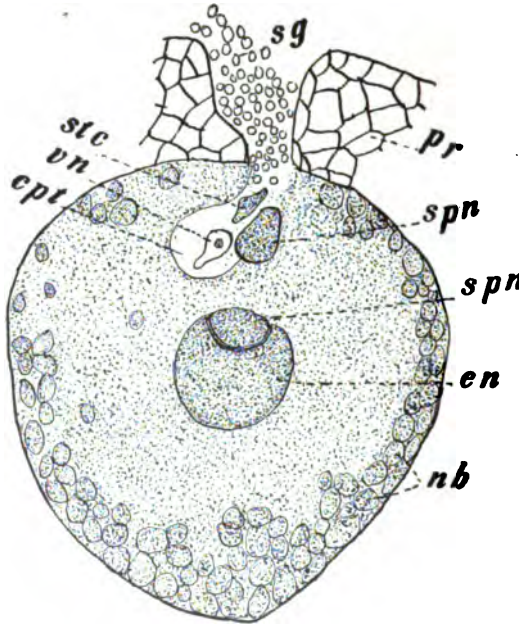


Fig. 361.

Archegonium of white pine at stage of fertilization. *en*, egg nucleus; *spn*, sperm nucleus in conjugation with it; *nb*, nutritive bodies in cytoplasm of large egg; *cpt*, cavity of pollen tube; *vn*, vegetative nucleus or tube nucleus; *sc*, stalk cell; *spn*, second sperm nucleus; *pr*, portion of prothallium or endosperm; *sg*, starch grains in pollen tube. The sheath of jacket cells of the archegonium is not shown. (After Ferguson.)

entire scale according to this view is a carpel, or sporophyll, which is divided into the cover scale and the ovuliferous scale. This division of the sporophyll is considered similar to that which we have in isoetes, where the sporophyll has a ligule above the sporangium, or as in ophioglossum, where the leaf is divided into a fertile and a sterile portion.

Others believe that the ovuliferous scale is composed of two leaves situated laterally and consolidated representing a shoot in the axis of the bract. There is some support for this in the fact that in certain abnormal cones which show proliferation a short axis appears in the axil of the bract and

bears lateral leaves, and in some cases all gradations are present between these lateral leaves on the axis and their consolidation into an ovuliferous scale. In the normal condition of the ovuliferous scale the axis has disappeared and the shoot is represented only by the consolidated leaves, which would represent then the macrosporophylls (or carpels) each bearing one macrosporangium (ovule).

One of the most interesting and plausible views is that of Celakovsky. He believes that the axial shoot is reduced to two ovules, that the ovules

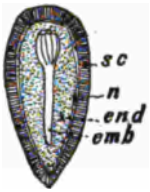


Fig. 362.

Pine seed, section of. *sc*, seed coat; *n*, remains of nucellus; *end*, endosperm (= female gametophyte); *emb*, embryo = young sporophyte. Seed coat and nucellus = remains of old sporophyte.

Fig. 363.

Embryo of white pine removed from seed, showing several cotyledons.

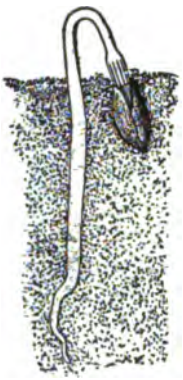


Fig. 364.

Pine seedling just emerging from the ground.

have two integuments, but the outer integument of each has become proliferated into scales which are consolidated. In this proliferation of the outer integument it is thrown off from the ovule so that it only remains attached to one side and the larger part of the ovule is thus left with only one integument. This view is supported by the fact that in gingko, for example (another gymnosperm), the outer integument (the "collar") sometimes proliferates into a leaf. Celakovsky's view is, therefore, not very different from the second one mentioned above.

Fig. 365.
White-pine seedling casting seed coats.

CHAPTER XXXIV.

FURTHER STUDIES ON GYMNOSPERMS.

Cycas.

627. In such gymnosperms as cycas, illustrated in the frontispiece, there is a close resemblance to the members of the fern group, especially the ferns themselves. This is at once suggested by the form of the leaves. The stem is short and thick. The leaves have a stout midrib and numerous narrow pinnæ. In the center of this rosette of leaves are numerous smaller leaves, closely overlapping like bud scales. If we remove one of these at the time the fruit is forming we see that in general it conforms to the plan of the large leaves. There are a midrib and a number of narrow pinnæ near the free end, the entire leaf being covered with woolly hairs. But at the lower end, in place of the pinnæ, we see oval bodies. These are the macrosporangia (ovules) of cycas, and correspond to the macrosporangia of selaginella, and the leaf is the macrosporophyll.

Fig. 366. Macrosporophyll of Cycas revoluta.

628. Female prothallium of cycas.—In figs. 367, 368, are shown mature ovules, or macrosporangia, of cycas. In 368, which is a roentgen-ray photograph of 367, the oval prothallium can be seen. So in cycas, as in selaginella, the female prothallium is

developed entirely inside of the macrosporangium, and derives the nutriment for its growth from the cycas plant, which is the

Fig. 367.
Macrosporangium of Cycas revoluta

Fig. 368.
Roentgen photograph of same, showing female prothallium.

sporophyte. Archegonia are developed in this internal mass of cells. This aids us in determining that it is the prothallium. In cycas it is also called endosperm, just as in the pines.

629. If we cut open one of the mature ovules, we can see the endosperm (prothallium) as a whitish mass of tissue. Immediately surrounding it at maturity is a thin, papery tissue, the remains of the nucellus (macrosporangium), and outside of this are the coats of the ovule, an outer fleshy one and an inner stony one.

630. Microspores, or pollen, of cycas.—The cycas plant illustrated in the frontispiece is a female plant. Male plants also exist which have small leaves in the center that bear

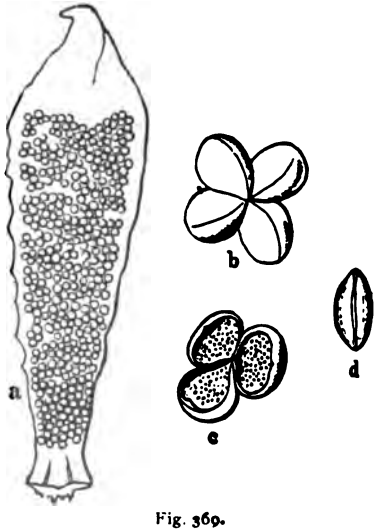


Fig. 369.
A sporophyll (stamen) of cycas; sporangia in groups on the under side. *b*, group of sporangia; *c*, open sporangia. (From Warming.)

only microsporangia. These leaves, while they resemble the ordinary leaves, are smaller and correspond to the stamens. Upon the under side, as shown in fig. 369, the microsporangia are borne in groups of three or four, and these contain the microspores, or pollen grains. The arrangement of these microsporangia on the under side of the cycas leaves bears a strong resemblance to the arrangement of the sporangia on the under side of the leaves of some ferns.

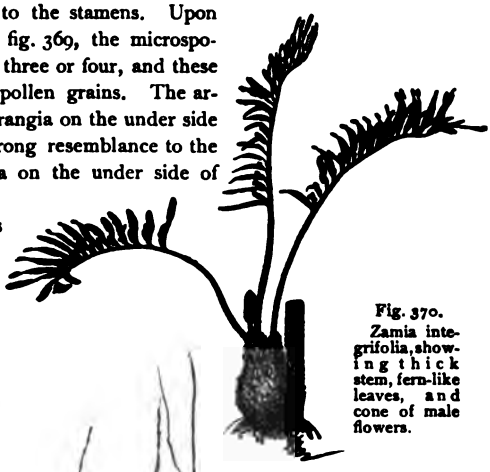


Fig. 370.
Zamia integrifolia, showing thick stem, fern-like leaves, and cone of male flowers.

631. The gingko tree is another very interesting plant belonging to this same group. It is a relic of a genus which flourished in the remote past, and it is interesting also because of the resemblance of the leaves to some of the ferns like adiantum, which suggests that this form of the leaf in gingko has been inherited from some fern-like ancestor.

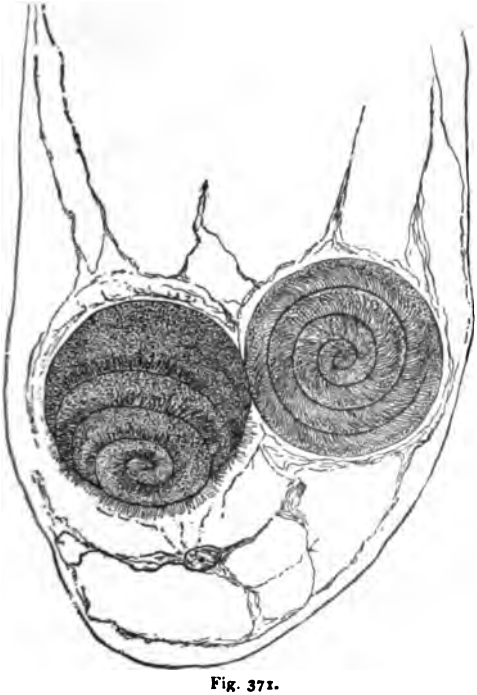


Fig. 371.
Two spermatozoids in end of pollen tube of cycas. (After drawing by Hirase and Ikeno.)

632. While the resemblance of the leaves of some of the gymnosperms to those of the ferns suggests fern-like ancestors for the members of this group, there is stronger evidence of such ancestry in the fact that a prothallium can well be determined in the ovules. The endosperm with its well-formed archegonia is to be considered a prothallium.

633. Spermatozoids in some gymnosperms.—But within the past two years it has been discovered in gingko, cycas, and zamia, all belonging to this

group, that the sperm cells are well-formed spermatozoids. In zamia each one is shaped somewhat like the half of a biconvex lens, and around the convex surface are several coils of cilia. After the pollen tube has grown down through the nucellus, and has reached a depression at the end of the prothallium (endosperm) where the archegonia are formed, the spermatozoids are set free from the pollen tube, swim around in a liquid in this depression, and later fuse with the egg. In gingko and cycas these spermatozoids were first discovered by Ikeno and Hirase in Japan, and later in zamia by Webber in this country. In figs. 371–374 the details of the male prothallia and of fertilization are shown.

Fig. 372.

Fertilization in cycas, small spermatozoid fusing with the larger female nucleus of the egg. The egg protoplasm fills the archegonium. (From drawings by Hirase and Ikeno.)

634. The sporophyte in the gymnosperms.—In the pollen grains of the gymnosperms we easily recognize the characters belonging to the spores in the ferns and their allies, as well as in the liverworts and mosses. They belong to the same series of organs, are borne on the same phase or generation of the plant, and are practically formed in the same general way, the variations between the different groups not being greater than those within a single group. These spores we have recognized as being the product of the sporophyte. We are able then to identify the sporophyte as that phase or generation of the plant formed from the fertilized egg and bearing ultimately the spores. We see from this that the sporophyte in the gymnosperms is the prominent part of the plant, just as we found it to be in the ferns. The pine tree, then, as well as the gingko, cycas, yew, hemlock-spruce, black spruce, the giant redwood of California, etc., are sporophytes.

Fig. 373.

Spermatozoid of gingko. Some abnormal forms have a tail. (After Ikeno and Hirase.)

While the sporangia (anther sacs) of the male flowers open and permit the spores (pollen) to be scattered, the sporangia of the female flowers of the gymnosperms rarely open. The macrospore is developed within sporangium (nucellus) to form the female prothallium (endosperm).

635. The gametophyte has become dependent on the sporophyte.—In this respect the gymnosperms differ widely from the pteridophytes, though we see suggestions of this condition of things in Isoetes and Selaginella, where the female prothallium is developed within the macrospore, and even in Selaginella begins, and nearly completes, its development while still in the sporangium.

In comparing the female prothallium of the gymnosperms with that of the fern group we see a remarkable change has taken place. The female prothallium of the gymnosperms is very much reduced in size. Especially, it no longer leads an independent existence from the sporophyte, as is the case with nearly all the fern group. It remains enclosed within the macrosporangium (in cycas if not fertilized it sometimes grows outside of the macrosporangium and becomes green), and derives its nourishment through it from the sporophyte, to which the latter remains organically connected. This condition of the female prothallium of the gymnosperms necessitated a special adaptation of the male prothallium in order that the sperm cells may reach and fertilize the egg cell.

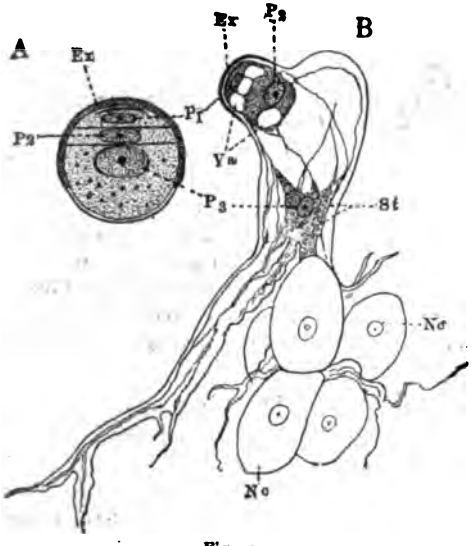


Fig. 374.

Gingko biloba. *A*, mature pollen grain; *B*, germinating pollen grain, the branched tube entering among the cells of the nucellus; *Ex*, exine (outer wall of spore); P_1, prothallial cell; P_2, antheridial cell (divides later to form stalk cell and generative cell); P_3, vegetative cell; *Va*, vacuoles; *Nc*, nucellus. (After drawings by Hirase and Ikeno.)

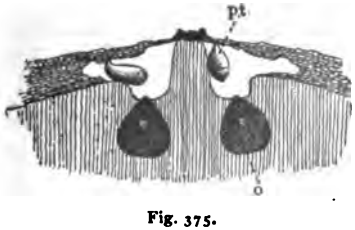


Fig. 375.

Gingko biloba, diagrammatic representation of the relation of pollen tube to the archegonium in the end of the nucellus. *pt*, pollen tube; *o*, archegonium. (After drawing by Hirase and Ikeno.)

636. Gymnosperms are naked seed plants.—The pine, as we have seen, has naked seeds. That is, the seeds are not enclosed within the carpel, but

are exposed on the outer surface. All the plants of the great group to which the pine belongs have naked seeds. For this reason the name "*gymnosperms*" has been given to this great group.

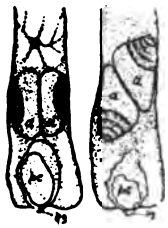


Fig. 376.

Spermatozoids of zamia in pollen tube; *pg*, pollen grain; *a*, *a*, spermatozoids. (After Webber.)

Fig. 377.

Spermatozoid of zamia showing spiral row of cilia. (After Webber.)

637. Classification of gymnosperms.—The gingko tree has until recently been placed with the pines, yew, etc., in the order *Pinales*, but the discovery of the spermatozoids in the pollen tube suggests that it is not closely allied with the Pinales, and that it represents an order coordinate with them. Engler arranges the living gymnosperms somewhat as follows:

Class Gymnospermæ.

Order 1. Cycadales; family Cycadaceæ. Cycas, Zamia, etc.

Order 2. Gingkoales; family Gingkoaceæ. Gingko.

Order 3. Pinales (or Coniferæ); family 1. Taxaceæ. Taxus, the common yew in the eastern United States, and Torreya, in the western United States, are examples.

family 2. Pinaceæ. Sequoia (redwood of California), firs, spruces, pines, cedars, cypress, etc.

Order 4. Gnetales. Welwitschia mirabilis, deserts of southwest Africa; Ephedra, deserts of the Mediterranean and of West Asia. Gnetum, climbers (Lianas), from tropical Asia and America.

641. Corolla.—Next above the calyx is a whorl of white or pinkish members, in Trillium grandiflorum, which are also leaf-like in form, and broader than the sepals, being usually somewhat broader at the free end. These make up what is the *corolla* in the higher plants, and each member of the corolla is a *petal*. But while they are parts of the flower, and are not green, their form and position would suggest that they also belong to the leaf series.

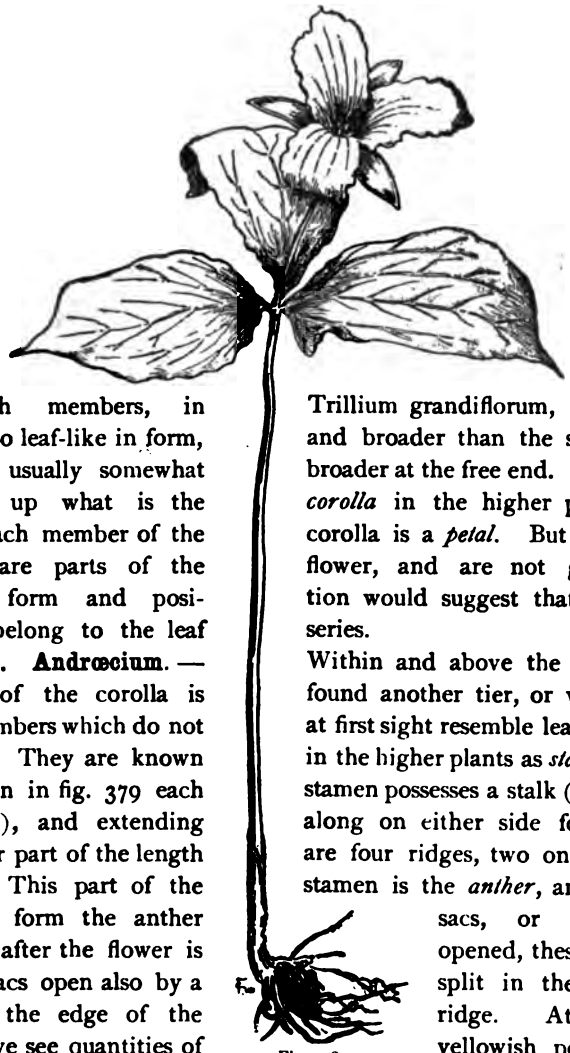


Fig. 378.
Trillium grandiflorum.

642. Androecium.—Within and above the insertion of the corolla is found another tier, or whorl, of members which do not at first sight resemble leaves in form. They are known in the higher plants as *stamens*. As seen in fig. 379 each stamen possesses a stalk (= filament), and extending along on either side for the greater part of the length are four ridges, two on each side. This part of the stamen is the *anther*, and the ridges form the anther sacs, or lobes. Soon after the flower is opened, these anther sacs open also by a split in the wall along the edge of the ridge. At this time we see quantities of yellowish powder or dust escaping from the ruptured anther locules. If we place some of this under the microscope we see

that it is made up of minute bodies which resemble spores; they are rounded in form, and the outer wall is spiny. They are in fact spores, the microspores of the trillium, and here, as in the gymnosperms, are better known as *pollen*.

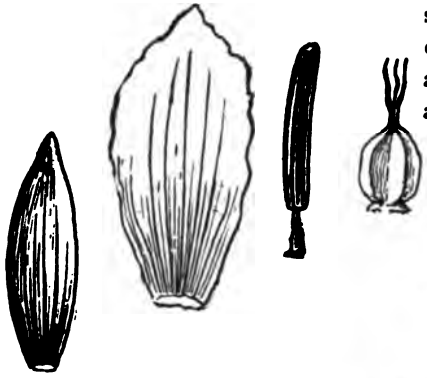


Fig. 379.
Sepal, petal, stamen, and pistil of Trillium grandiflorum.

643. The stamen a sporophyll.—Since these pollen grains are the spores, we would infer, from what we have learned of the ferns and gymnosperms, that this member of the flower which bears them is a sporophyll; and this is the case. It is in fact what is called the *microsporophyll*. Then we see also that the anther sacs, since they enclose the spores, would be the sporangia (microsporangia). From this it is now quite clear that the stamens belong also to the leaf series. They are just six in number, twice the number found in a whorl of leaves, or sepals, or corolla. It is believed, therefore, that there are two whorls of stamens in the flower of trillium.

Fig. 380.
Trillium grandiflorum, with the compound pistil expanded into three leaf-like members. At the right these three are shown in detail.

644. Gynœcium.—Next above the stamens and at the center of the flower is a stout, angular, ovate body which terminates in three long, slender, curved points. This is the pistil, and at

present the only suggestion which it gives of belonging to the leaf series is the fact that the end is divided into three parts, the number of parts in each successive whorl of members of the flower. If we cut across the body of this pistil and examine it with a low power we see that there are three chambers or cavities, and at the junction of each the walls suggest to us that this body may have been formed by the infolding of the margins of three leaf-like members, the places of contact having then become grown together. We see also that from the incurved margins of each division of the pistil there stand out in the cavity oval bodies. These are the *ovules*. Now the ovules we have learned from our study of the gymnosperms are the *sporangia* (here the macrosporangia).

Fig. 381. Abnormal trillium. The nine parts of the perianth are green, and the outer whorls of stamens are expanded into petal-like members.

It is now more evident that this curious body, the pistil, is made up of three leaf-like members which have fused together, each member being the equivalent of a sporophyll (here the macrosporophyll). This must be a fascinating observation, that plants of such widely different groups and of such different grades of complexity should have members formed on the same plan and belonging to the same series of members, devoted to similar functions, and yet carried out with such great modifications that at first we do not see this common meeting ground which a comparative study brings out so clearly.

Fig. 382. Transformed stamen of trillium showing anther locules on the margin.

645. Transformations of the flower of trillium.— If anything more were needed to make it clear that the parts of the flower of trillium belong to the leaf series we could obtain evidence from the transformations which

the flower of trillium sometimes presents. In fig. 381 is a sketch of a flower of trillium, made from a photograph. One set of the stamens has expanded into petal-like organs, with the anther sacs on the margin. In fig. 380 is shown a plant of Trillium grandiflorum in which the pistil has separated into three distinct and expanded leaf-like structures, all green except portions of the margin.

Dentaria.

646. General appearance.—For another study we may take a plant which belongs to another division of the higher plants, the common "pepper root," or "toothwort" (Dentaria diphylla) as it is sometimes called. This plant occurs in moist woods during the month of May, and is well distributed in the northeastern United States. A plant is shown in fig. 383. It has a creeping underground rhizome, whitish in color, fleshy, and with a few scales. Each spring the annual flower-bearing stem rises from one of the buds of the rhizome, and after the ripening of the seeds, dies down.

The leaves are situated a little above the middle point of the stem. They are opposite and the number is two, each one being divided into three dentate lobes, making what is called a compound leaf.

647. Parts of the flower.—The flowers are several, and they are borne on quite long stalks (pedicels) scattered over the terminal portion of the stem. We should now examine the parts of the flower beginning with the calyx. This we can see, looking at the under side of some of the flowers, possesses four scale-like sepals, which easily fall away after the opening of the flower. They do not resemble leaves so much as the sepals of trillium, but they belong to the leaf series, and there are two pairs in the set of four. The corolla also possesses four petals, which are more expanded than the sepals and are whitish in color. The stamens are six in number, one pair lower than the others, and also

shorter. The filament is long in proportion to the anther, the latter consisting of two lobes or sacs, instead of four as in trillium. The pistil is composed of two carpels, or leaves fused together. So we find in the case of the pepper root that the parts of the flower are in twos, or multiples of two. Thus they agree in this respect with the leaves; and while we do not see such a strong resemblance between the parts of the flower here and the leaves, yet from the presence of the pollen

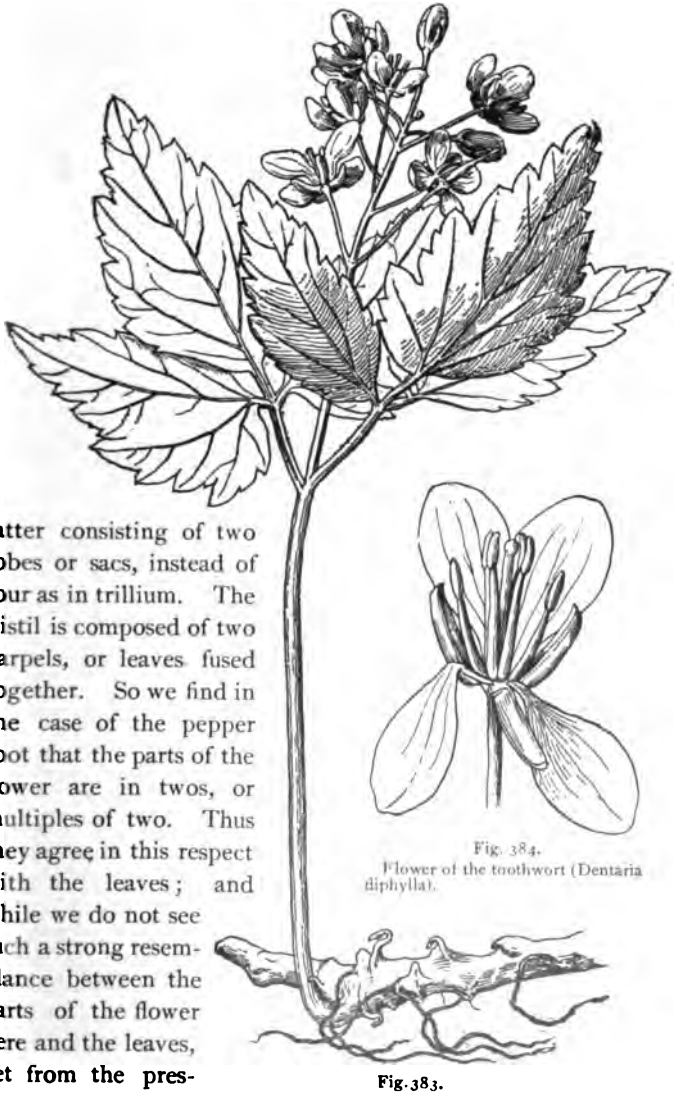


Fig. 384.
Flower of the toothwort (Dentaria diphylla).

Fig. 383.
Toothwort (Dentaria diphylla).

(microspores) in the anther sacs (microsporangia) and of ovules (macrosporangia) on the margins of each half of the pistil, we are, from our previous studies, able to recognize here that all the members of the flower belong to the leaf series.

648. In trillium and in the pepper root we have seen that the parts of the flower in each apparent whorl are either of the same number as the leaves in a whorl, or some multiple of that number. This is true of a large number of other plants, but it is not true of all. A glance at the spring beauty (Claytonia virginiana, and at the anemone (or Isopyrum biternatum, fig. 563) will serve to show that the number of the different members of the flower may vary. The trillium and the dentaria were selected as being good examples to study first, to make it very clear that the members of the flower are fundamentally leaf structures, or rather that they belong to the same series of members as do the leaves of the plant.

649. Synopsis of members of the sporophyte in angiosperms.

Higher plant. Sporophyte phase (or modern phase). } Root. Shoot. } Stem. Leaf. { Foliage leaves. Perianth leaves. Spore-bearing leaves with sporangia. (Sporangia sometimes on shoot.) } Flower.

CHAPTER XXXVI.

GAMETOPHYTE AND SPOROPHYTE OF ANGIOSPERMS.

650. Male prothallium of angiosperms.—The first division which takes place in the nucleus of the pollen grain occurs, in the case of trillium and many others of the angiosperms, before the pollen grain is mature. In the case of some specimens of T. grandiflorum in which the pollen was formed during the month of October of the year before flowering, the division of the nucleus into two nuclei took place soon after the formation of the four cells from the mother cell. The nucleus divided in the young pollen grain is shown in fig. 385. After this takes place the wall of the pollen grain becomes stouter, and minute spiny projections are formed.

Fig. 385.

Nearly mature pollen grain of trillium. The smaller cell is the generative cell.

651. The larger cell is the vegetative cell of the prothallium, while the smaller one, since it later forms the sperm cells, is the generative cell. This generative cell then corresponds to the central cell of the antheridium, and the vegetative cell perhaps corresponds to a wall cell of the antheridium. If this is so, then the male prothallium of angiosperms has become reduced to a very simple antheridium. The farther growth takes place after fertilization. In some plants the generative cell divides into the two sperm cells at the maturity of the pollen grain. In other cases the generative cell divides in the pollen tube after the germination of the pollen grain. For study of the pollen tube the pollen may be germinated in a weak solution of sugar, or on the cut surface

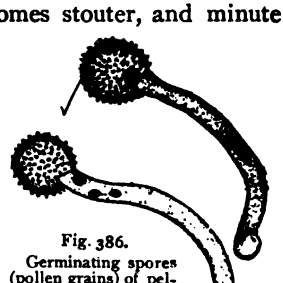


Fig. 386.

Germinating spores (pollen grains) of peltandra; generative nucleus in one undivided, in other divided to form the two sperm nuclei; vegetative nucleus in each near the pollen grain.

of pear fruit, the latter being kept in a moist chamber to prevent drying the surface.

652. In the spring after flowering the pollen escapes from the anther sacs, and as a result of pollination is brought to rest on the stigma of the pistil. Here it germinates, as we say, that is, it develops a long tube which makes its way down through the style, and in through the micropyle to the embryo sac, where, in accordance with what takes place in other plants examined, one of the sperm cells unites with the egg, and fertilization of the egg is the result.

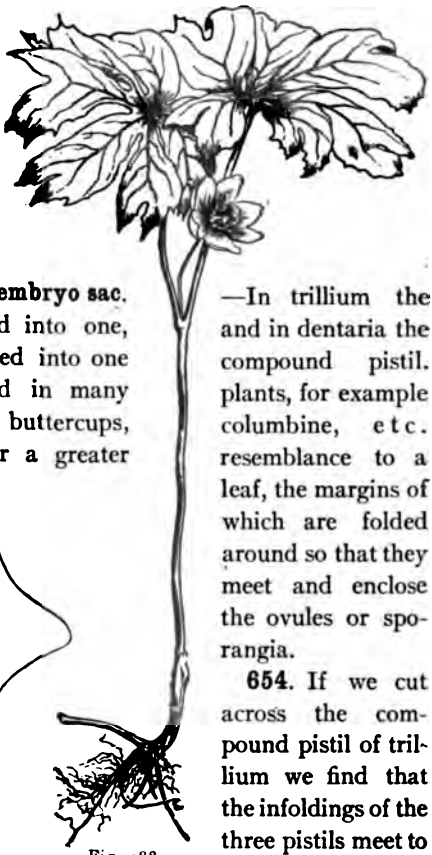


Fig. 388. Mandrake (Podophyllum peltatum).

653. Macrospore and embryo sac.—In trillium the three carpels are united into one, and in dentaria the two carpels are also united into one compound pistil. Simple pistils are found in many plants, for example in the ranunculaceæ, the buttercups, columbine, etc. These simple pistils bear a greater resemblance to a leaf, the margins of which are folded around so that they meet and enclose the ovules or sporangia.

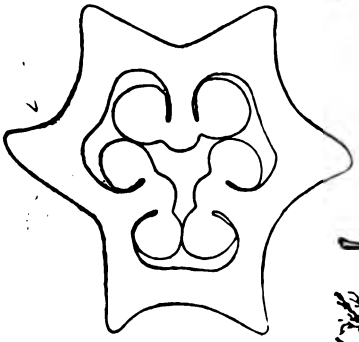


Fig. 387. Section of pistil of trillium, showing position of ovules (macrosporangia).

654. If we cut across the compound pistil of trillium we find that the infoldings of the three pistils meet to form three partial partitions which extend nearly to the center, dividing off three spaces. In these spaces are the ovules which are attached to the infolded margins. If we make cross sections of a pistil of the May-apple (podo-

phyllum) and through the ovules when they are quite young, we shall find that the ovule has a structure like that shown in fig. 389. At *m* is a cell much larger than the surrounding ones. This is called the macrospore. The tissue surrounding it is called here the nucellus, but because it contains the macrospore it must be the macrosporangium. The two coats or integuments of the ovule are yet short and have not grown out over the end of the nucellus. This macrospore increases in size, forming first a cavity or sac in the nucellus, the *embryo sac*. The nucleus divides several

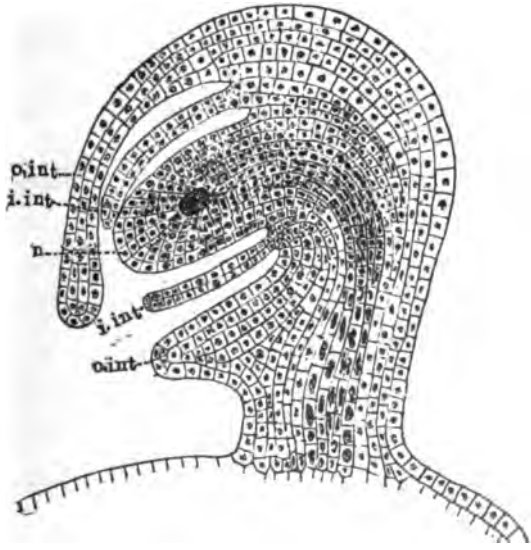


Fig. 389.

Young ovule (macrosporangium) of podophyllum. *n*, nucellus containing the one-celled stage of the macrospore; *i.int*, inner integument; *o.int*, outer integument.

times until eight are formed, four in the micropylar end of the embryo sac and four in the opposite end. In some plants it has been found that one nucleus from each group of four moves toward the middle of the embryo sac. Here they fuse together to form one nucleus, the *endosperm nucleus* or *definitive nucleus* shown in fig. 390. One of the nuclei at the micropylar end is the egg, while the two smaller ones nearer the end are the *syner-*

gids. The egg cell is all that remains of the archegonium in this reduced prothallium. The three nuclei at the lower end are the *antipodal* cells.

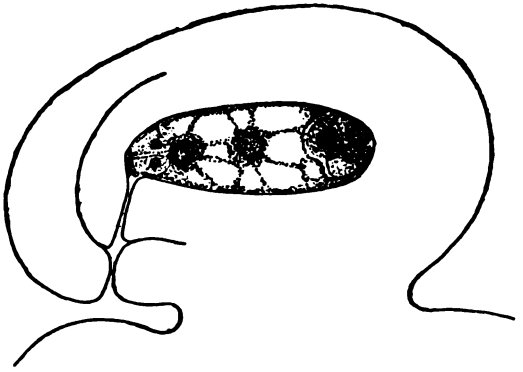


Fig. 390.
Podophyllum peltatum, ovule containing mature embryo sac; two synergids, and eggs at left, endosperm nucleus in center, three antipodal cells at right.

655. Embryo sac is the young female prothallium.—In figs. 391–393 are shown the different stages in the development of the embryo sac in lilium. The embryo sac at this stage is the young female prothallium, and the egg is the only remnant of the female sexual organ, the archegonium, in this reduced gametophyte.

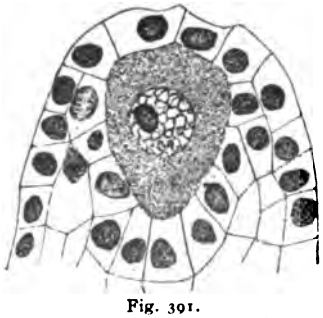


Fig. 391.
Macrospore (one-celled stage) of lilium.

656. Fertilization.—When the pollen tube has reached the embryo sac (paragraph 652) it opens and the two sperm cells are emptied near the egg. The first sperm nucleus enters the protoplasm surrounding the egg nucleus and uniting with the latter brings about fertilization. The second sperm nucleus often unites with the endosperm nucleus (or with one or both of the "polar nuclei"), bringing about what some call a second fertilization. Where this takes place in addition to the union of the first sperm

nucleus with the egg nucleus it is called *double fertilization.* The sperm nucleus is usually smaller than the egg nucleus, but often grows to near or quite the size of the egg nucleus before union. See figs. 394 and 395.

657. Fertilization in plants is fundamentally the same as in animals.—In all the great groups of plants as represented by spirogyra, œdogonium, vaucheria, peronospora, ferns, gymno-

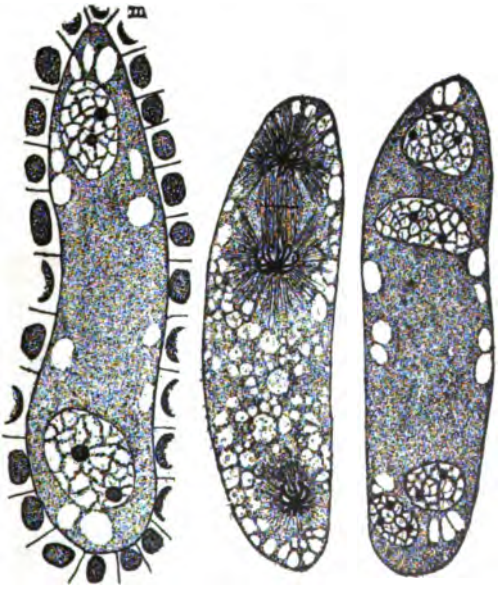


Fig. 392.

Two- and four-celled stage of embryo-sac of lilium. The middle one shows division of nuclei to form the four-celled stage. (Easter lily.)

sperms, and in the angiosperms, fertilization, as we have seen, consists in the fusion of a male nucleus with a female nucleus. Fertilization, then, in plants is identical with that which takes place in animals.

658. Embryo.—After fertilization the egg develops into a short row of cells, the *suspensor* of the embryo. At the free end the embryo develops. In figs. 397 and 398 is a young embryo of trillium.

659. Endosperm, the mature female prothallium.—During the development of the embryo the endosperm nucleus divides

into a great many nuclei in a mass of protoplasm, and cell walls are formed separating them into cells. This mass of cells is the *endosperm*, and it surrounds the embryo. It is the *mature female prothallium*, belated in its growth in the angiosperms, usually developing only when fertilization takes place, and its use has been assured.

660. Seed.—As the embryo

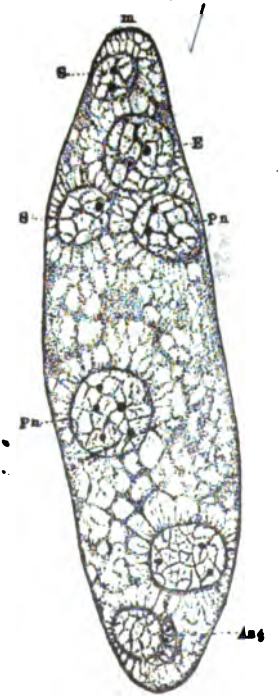


Fig. 393.

Mature embryo sac (young prothallium) of lilium. *m*, micropylar end; *S*, synergids; *E*, egg; *Pn*, polar nuclei; *Ant*, antipodals. (Easter lily.)

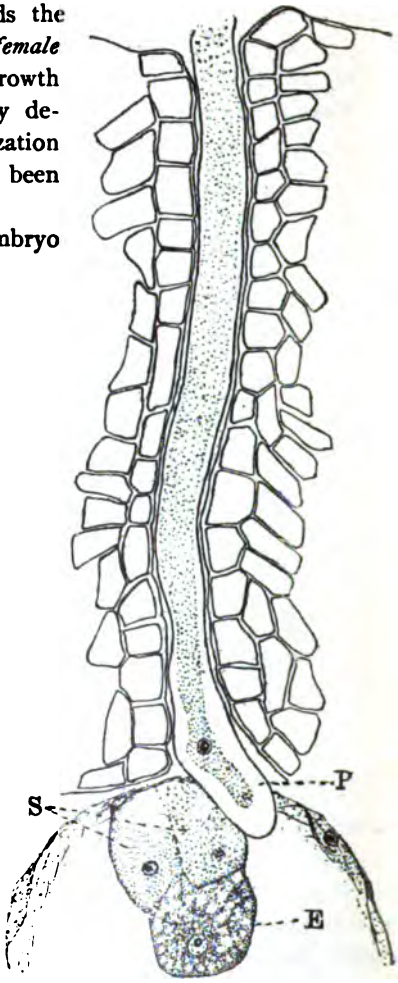


Fig. 394.

Section through nucellus and upper part of embryo sac of cotton at time of entrance of pollen tube. *E*, egg; *S*, synergids; *P*, pollen tube with sperm cell in the end. (Duggar.)

is developing it derives its nourishment from the endosperm (or in some cases perhaps from the nucellus). At the same time

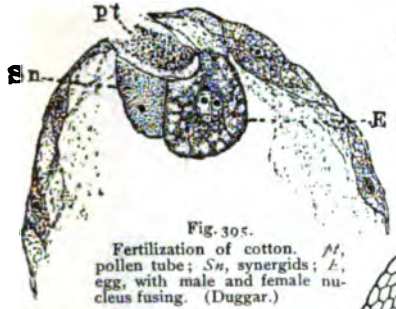


Fig. 395.
Fertilization of cotton. *pt*, pollen tube; *Sn*, synergids; *E*, egg, with male and female nucleus fusing. (Duggar.)

the integuments increase in extent and harden as the seed is formed.

661. Perisperm. — In most plants the nucellus is all consumed in the development of the endosperm, so that only minute fragments of disorganized cell walls remain next the inner integument. In some plants, however, (the water-lily family, the pepper family, etc.,) a portion of the nucellus remains intact in the mature seed. In such seeds the remaining portion of the nucellus is the *perisperm*.

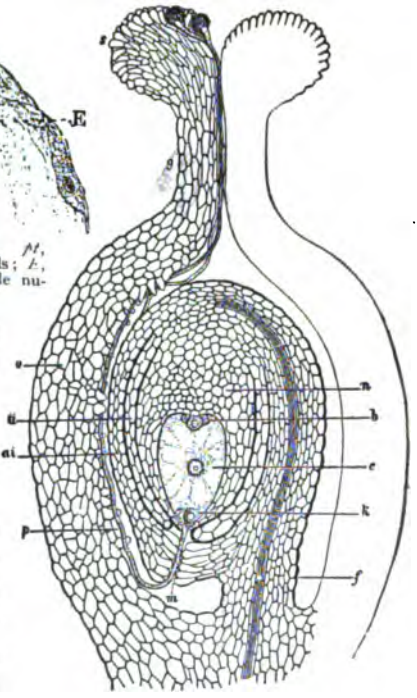


Fig. 396.
Diagrammatic section of ovary and ovule at time of fertilization in angiosperm. *f*, funicle of ovule; *n*, nucellus; *m*, micropyle; *b*, antipodal cells of embryo sac; *c*, endosperm nucleus; *k*, egg cell and synergids; *ai*, outer integument of ovule; *ii*, inner integument. The track of the pollen tube is shown down through the style, walls of the ovary to the micropylar end of the embryo sac.

662. Presence or absence of endosperm in the seed.—In many of the angiosperms all of the endosperm is consumed by the embryo during its growth in the formation of the seed. This is the case in the rose family, crucifers, composites, willows, oaks, legumes, etc., as in the acorn, the bean, pea and others. In some, as in the bean, a large part of the nutrient substance pass-

ing from the endosperm into the embryo is stored in the cotyledons for use during germination. In other plants the endosperm

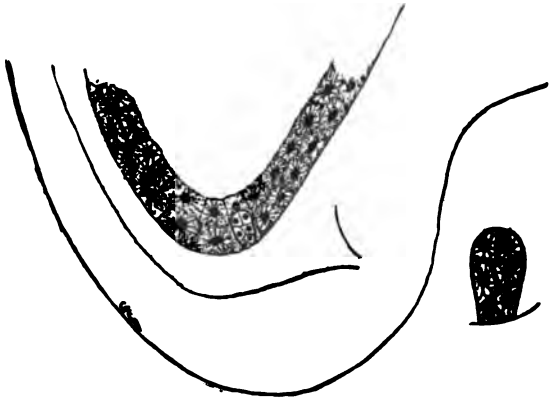


Fig. 397.
Section of one end of ovule of trillium, showing young embryo in endosperm.

Fig. 398.
Embryo enlarged.

is not all consumed by the time the seed is mature. Examples of this kind are found in the buttercup family, the violet, lily, palm,

Fig. 399.
Seed of violet, external view, and section. The section shows the embryo lying in the endosperm.

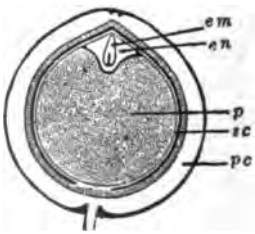


Fig. 400.
Section of fruit of pepper (Piper nigrum), showing small embryo lying in a small quantity of whitish endosperm at one end, the perisperm occupying the larger part of the interior, surrounded by pericarp.

jack-in-the-pulpit, etc. Here the remaining endosperm in the seed is used as food by the embryo during germination.

663. Outer parts of the seed.—While the embryo is forming

within the ovule and the growth of the endosperm is taking place, where this is formed, other correlated changes occur in the outer parts of the ovule, and often in adjacent parts of the flower. These unite in making the "seed," or the "fruit." Especially in connection with the formation of the seed a new growth of the outer coat, or integument, of the ovule occurs, forming the outer coat of the seed, known as the *testa*, while the inner integument is absorbed. In some cases the inner integument of the ovule also forms a new growth, making an inner coat of the seed (rosaceæ). In still other cases neither of the integuments develops into a testa, and the embryo sac lies in contact with the wall of the ovary. Again an additional envelope grows up around the seed; an example of this is found in the case of the red berries of the "yew" (taxus), the red outer coat being an extra growth, called an *aril*.

In the willow and the milkweed an aril is developed in the form of a tuft of hairs. (In the willow it is an outgrowth of the funicle, = stalk of the ovule, and is called a funicular aril; while in the milkweed it is an outgrowth of the micropyle, = the open end of the ovule, and is called a micropylar aril.)

664. Increase in size during seed formation.—Accompanying this extra growth of the different parts of the ovule in the formation of the seed is an increase in the size, so that the seed is often much greater in size than the ovule at the time of fertilization. At the same time parts of the ovary, and in many plants, the adherent parts of the floral envelopes, as in the apple; or of the receptacle, as in the strawberry; or in the involucre, as in the acorn; are also stimulated to additional growth, and assist in making the fruit.

665. Synopsis of the seed.

- *The seed.*
  - *Ripened ovule.*
    - Aril, rarely present.
    - Ovular coats (one or two usually present), the *testa.*
    - *Funicle* (stalk of ovule), *raphe* (portion of funicle when bent on to the side of ovule), *micropyle*, *hilum* (scar where seed was attached to ovary).
    - *Remnant of the nucellus* (central part of ovule); sometimes nucellus remains as
    - *Perisperm* in some albuminous seeds.
  - *Endosperm*, present in albuminous seeds.
  - *Embryo* within surrounded by endosperm when this is present, or by the remnant of nucellus, and by the ovular coats which make the *testa.* In many seeds (example, bean) the endosperm is transferred to the cotyledons which become fleshy (exalbuminous seeds).

666. Parts of the ovule.—In fig. 401 are represented three different kinds of ovules, which depend on the position of the

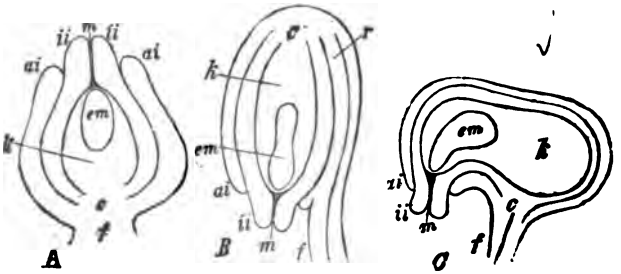


Fig. 401.

A, represents a straight (orthotropous) ovule of polygonum; *B*, the inverted (anatropous) ovule of the lily; and *C*, the right-angled (campylotropus) ovule of the bean. *f*, funicle; *c*, chalaza; *k*, nucellus; *ai*, outer integument; *ii*, inner integument; *m*, micropyle; *em*, embryo sac.

ovule with reference to its stalk. The funicle is the stalk of the ovule, the hilum is the point of attachment of the ovule with the ovary, the raphe is the part of the funicle in contact with the ovule in inverted ovules, the chalaza is the portion of the ovule where the nucellus and the integuments merge at the base of the ovule, and the micropyle is the opening at the apex of the ovule where the coats do not meet.

Comparison of Organ and Member.

667. The stamens and pistils are not the sexual organs.—Before the sexual organs and sexual processes in plants were properly understood it was customary for botanists to speak of the stamens and pistils of flowering plants as the sexual organs. Some of the early botanists, a century ago, found that in many plants the seed would not form unless first the pollen from the stamens came to be deposited on the stigma of the pistil. A little further study showed that the pollen germinated on the stigma and formed a tube which made its way down through the pistil and into the ovule.

This process, including the deposition of the pollen on the stigma, was supposed to be fertilization, the stamen was looked on as the male sexual organ, and the pistil as the female sexual organ. We have found out, however, by further study, and especially by a comparison of the flowering plants and the lower plants, that the stamens and pistils are not the sexual organs of the flower.

668. The stamens and pistils are spore-bearing leaves.—The stamen is the spore-bearing leaf, and the pollen grains are not unlike spores; in fact they are the small spores of the angiosperms. The pistil is also a spore-bearing leaf, the ovule the sporangium, which contains the large spore called an *embryo sac.* In the ferns we know that the spore germinates and produces the green heart-shaped prothallium. The prothallium bears the sexual organs. Now the fern leaf bears the spores and the spore forms the prothallium. So it is in the flowering plants. The stamen bears the small spores—pollen grains—and the pollen grain forms the prothallium. The prothallium in turn forms the sexual organs. The process is in general the same as it is in the ferns, but with this special difference: the prothallium and the sexual organ of the flowering plants are very much reduced.

669. Difference between organ and member.—While it is not strictly correct then to say that the stamen is a sexual organ,

or male organ, we might regard it as a *male member* of the flower, and we should distinguish between *organ* and *member*. It is an *organ* when we consider *pollen production*, but it is not a sexual organ. When we consider *fertilization* it is *not a sexual organ, but a male member* of the flower which bears the small spore.

The following table will serve to indicate these relations.

Stamen = spore-bearing leaf = male member of flower.
Anther locule = sporangium.
Pollen grain = small spore = reduced male prothallium and sexual organ.

So the pistil is not a sexual organ, but might be regarded as the female member of the flower.

Pistil = spore-bearing leaf = female member of flower.
Ovule = sporangium.
Embryo sac = large spore = female prothallium containing the egg.
The egg = a reduced archegonium = the female sexual organ.

Progression and Retrogression in Sporophyte and Gametophyte.

670. Sporophyte is prominent and highly developed.—In the angiosperms then, as we have seen from the plants already studied, the trillium, dentaria, etc., are sporophytes, that is they represent the spore-bearing, or sporophytic, stage. Just as we found in the case of the gymnosperms and ferns, this stage is the prominent one, and the one by which we characterize and recognize the plant. We see also that the plants of this group are still more highly specialized and complex than the gymnosperms, just as they were more specialized and complex than the members of the fern group. From the very simple condition in which we possibly find the sporophyte in some of the algæ like spirogyra, vaucheria, and coleochæte, there has been a gradual increase in size, specialization of parts, and complexity of structure through the bryophytes, pteridophytes, and gymnosperms, up to the highest types of plant structure found in the angiosperms. Not only do we find that these changes have taken place, but we see that, from a condition of complete dependence of the spore-bearing stage on the sexual stage (gametophyte), as we find it in the liverworts and mosses, it first becomes free from the gametophyte in the members of the fern group, and is here able to lead an independent existence. The sporophyte, then, might be regarded as the modern phase of plant life,

since it is that which has become and remains the prominent one in later times.

671. The gametophyte once prominent has become degenerate.—On the other hand we can see that just as remarkable changes have come upon the other phase of plant life, the sexual stage, or gametophyte. There is reason to believe that the gametophyte was the stage of plant life which in early times existed almost to the exclusion of the sporophyte, since the characteristic thallus of the algæ is better adapted to an aquatic life than is the spore-bearing state of plants. At least, we now find in the plants of this group as well as in the liverworts, that the gametophyte is the prominent stage. When we reach the members of the fern group, and the sporophyte becomes independent, we find that the gametophyte is decreasing in size, in the higher members of the pteridophytes, the male prothallium consisting of only a few cells, while the female prothallium completes its development still within the spore wall. And in selaginella it is entirely dependent on the sporophyte for nourishment.

672. As we pass through the gymnosperms we find that the condition of things which existed in the bryophytes has been reversed, and the gametophyte is now entirely dependent on the sporophyte for its nourishment, the female prothallium not even becoming free from the sporangium, which remains attached to the sporophyte, while the remnant of a male prothallium, during the stage of its growth, receives nourishment from the tissues of the nucellus through which it bores its way to the egg-cell.

673. In the angiosperms this gradual degradation of the male and female prothallia has reached a climax in a one-celled male prothallium with two sperm-cells, and in the embryo-sac with no clearly recognizable traces of an archegonium to identify it as a female prothallium. The development of the endosperm subsequent, in most cases, to fertilization, providing nourishment for the sporophytic embryo at one stage or another, is believed to be the last remnant of the female prothallium in plants.

674. The seed.—The seed is the only important character possessed by the higher plants (the gymnosperms and angiosperms) which is not possessed by one or another of the lower great groups. With the gradual evolution of the higher plants from the lower there has been developed at certain periods organs or structural characters which were not present in some of the lower groups. Thus the thallus is the plant body of the algæ and fungi, so that these two groups of plants are sometimes called *Thallophytes.* In the Bryophytes (liverworts and mosses) the thallus is still present, but there is added the highly organized archegonium in place of the simple female gamete or oogonium, or carpogonium of the algæ and fungi, and the sporophyte has become a distinct though still dependent structure. In the Pteridophytes the thallus is still present as the prothallium, archegoina are also present, and while both of these structures are retrograding the sporophyte has become independent and has organized for the first time a true

vascular system for conduction of water and food. In the gymnosperms and angiosperms the thallus is present in the endosperm; distinct, though reduced, archegonia are present in most gymnosperms and represented only by the egg in the angiosperms; the vascular system is still more highly developed while the seed for the first time is organized, and characterizes these plants so that they are called seed plants, or *Spermatophytes*.

Variation, Hybridization, Mutation.

674a. Variation.—It is a well-known fact that plants as well as animals are subject to variation. Under certain conditions, some of which are partly understood and others are unknown, the progeny of plants differ in one or more characters from their parents. Some of these variations are believed to be due to the influence of environment (see Parts III and IV). Others are the result of the crossing of individuals which show greater or lesser differences in one or more characters, or the crossing of different species (*hybridization*). The most profound variations are those which spring suddenly into existence (*mutation*).

674b. Hybridization.—Two different species are "crossed" where the egg-cell of one species is fertilized by the sperm of another species. The progeny resulting from such a cross is a *hybrid*. Hybrids sometimes resemble one parent, sometimes another, sometimes both. Where the parents differ only in respect to one character of an organ or structure, there is a regular law in respect to the progeny if they are self-fertilized. In the first generation all the individuals are alike and resemble one of the parents, and the special differential character of that parent is called the *dominant* character. In the second generation 75% possess the dominant character, while 25% resemble the other original parent, and its differential character is called *recessive*. These are *pure* recessives, since successive generations, if self-fertilized, are always recessive. Of the 75% which show the dominant character in the second generation, one-third (or 25% of the whole number) are pure dominants if self-fertilization is continued, while 50% are really "cross breds" like the first generation, and if self-fertilized split up again into approximately 25 dominants, 50 cross breds, and 25 recessives. This is what is called Mendel's law. Where the original parents differ in respect to more than one character, the result is more complicated (see Mendel's Principles of Heredity; also de Vries, Das Spaltungsgesetz der Bastarde, Ber. d. deutsch. bot. Gesell., **18**, 83, 1900).

674c. Mutation.—This term is applied to those variations which appear so suddenly that some of the progeny of two like individuals differ from all the others to a marked degree. Some of these mutations are so different as to be regarded as new species. Some of the primroses show mutations, and Œnothera gigas is a mutation from Œnothera lamarkiana (see de Vries, Die Mutationstheorie, Leipzig)

the nucleus, giving rise to a succession of nuclear figures presented by a definite but variable series of evolutions on the part of the nuclear substance. This is *indirect division* of the nucleus, or *karyokinesis*. Indirect division of the nucleus is the usual method, and it occurs in the normal growth and division of the cell. The nuclear figures which are formed in the division of the mother cell into the four spores are somewhat different from those occurring in vegetative division, but their study will serve to show the general character of the process.

679. Chromatin and linin of the nucleus.—In figure 404 is represented a pollen mother cell of the May-apple (podophyl-

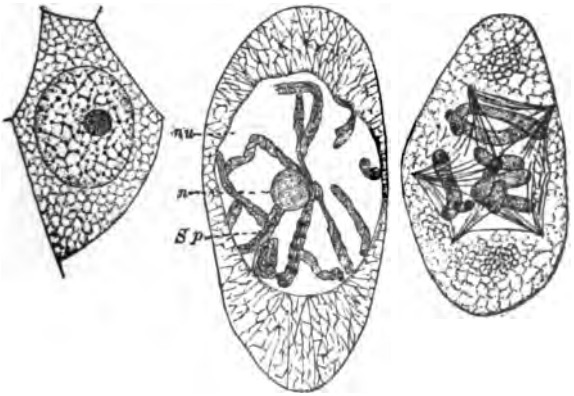


Fig. 404. Pollen mother cell of podophyllum, resting nucleus. Chromatin forming a network.

Fig. 405. Spirem stage of nucleus. *nu*, nuclear cavity; *n*, nucleolus; *Sp*, spirem.

Fig. 406. Forming spindle, threads from protoplasm with several poles, roping the chromosomes up to nuclear plate.

(Figures 404–406 after Mottier.)

lum). The nucleus is in the resting stage. There is a network consisting of very delicate threads, the *linin* network. Upon this network are numerous small granules, and at the junction of the threads are distinct knots. The nucleolus is quite large and prominent. The numerous small granules upon the linin stain very deeply when treated with certain dyes used in differentiating the nuclear structure. This deeply staining substance is the *chromatin* of the nucleus.

680. The chromatin skein.—One of the first nuclear figures in the preparatory stages of division is the chromatin *skein* or *spirem*. The chromatin substance unites to form this. The spirem is in the form of a narrow continuous ribbon, or band, woven into an irregular skein, or gnarl, as shown in figure 405. This band splits longitudinally into two narrow ones, and then each divides into a definite number of segments, about eight in the case of podophyllum. Sometimes the longitudinal splitting of the band appears to take place after the separation into the chromatin segments. The segments remain in pairs until they separate at the nuclear plate.

681. Chromosomes, nuclear plate, and nuclear spindle.—Each one of these rod-like chromatin segments is a *chromosome*.

Fig. 407.

Karyokinesis in pollen mother cells of podophyllum. At the left the spindle with the chromosomes separating at the nuclear plate; in the middle figure the chromosomes have reached the poles of the spindle, and at the right the chromosomes are forming the daughter nuclei. (After Mottier.)

The pairs of chromosomes arrange themselves in a median plane of the nucleus, radiating somewhat in a stellate fashion, forming the *nuclear plate*, or *monaster*. At the same time threads of the protoplasm (kinoplasm) become arranged in the form of a spindle, the axis of which is perpendicular to the nuclear plate of chromosomes, as shown in figure 407, at left. Each pair of chromosomes now separate in the line of the division of the original spirem, one chromosome of each pair going to one pole of the spindle,

while the other chromosome of each pair goes to the opposite pole. The chromosomes here unite to form the daughter nuclei.

Fig. 408.

Different stages in the separation of divided U-shaped chromosomes at the nuclear plate. (After Mottier.) In podophyllum.

Each of these nuclei now divide as shown in figure 409 (whether the chromosomes in this second division in the mother cell split longitudinally or divide transversely has not been definitely settled), and four nuclei are formed in the pollen mother cell. The protoplasm about each one of these four nuclei now surrounds itself with a wall and the spores are formed.

The number of chromosomes usually the same in a given species throughout one phase of the plant.—In those plants which have been carefully studied, the number of chromosomes in the dividing nucleus has been found to be fairly constant in a given species, through all the divisions in that stage or phase of the plant, especially in the embryonic, or young growing parts. For example, in the prothallium, or gametophyte, of certain ferns, as osmunda, the number of chromosomes in the dividing nucleus is always twelve. So in the development of the pollen of lilium from the mother cells, and in the divisions of the antherid cell to form the generative cells or sperm cells, there are always twelve chromosomes so far as has been found. In the development of the egg of lilium from the macrospore there are also twelve chromosomes.

Fig. 409.

Second division of nuclei in pollen mother cell of podophyllum. chromosomes at poles.

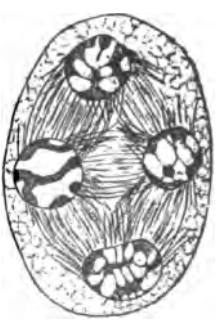


Fig. 410.

Chromosomes uniting at poles to form the nuclei of the four spores. (After Mottier.)

When fertilization takes place the number of chromosomes is doubled in the embryo.—In the spermatozoid of osmunda then, as well as in the egg, since these are developed on the gametophyte, there are twelve chromosomes each. The same is true in the sperm-cell (generative cell) of lilium, and also in the egg-cell. When these nuclei unite, as they do in fertilization, the paternal nucleus with the maternal nucleus, the number of chromosomes in the fertilized egg, if we take lilium as an example, is twenty-four instead of twelve; the number is doubled. The fertilized egg is the beginning of the sporophyte, as we have seen. Curiously throughout all the divisions of the nucleus in the embryonic tissues of the sporophyte, so far as has been determined, up to the formation of the mother cells of the spores, the number of chromosomes is usually the same

682. Reduction of the number of chromosomes in the nucleus.—If there were no reduction in the number of chromosomes

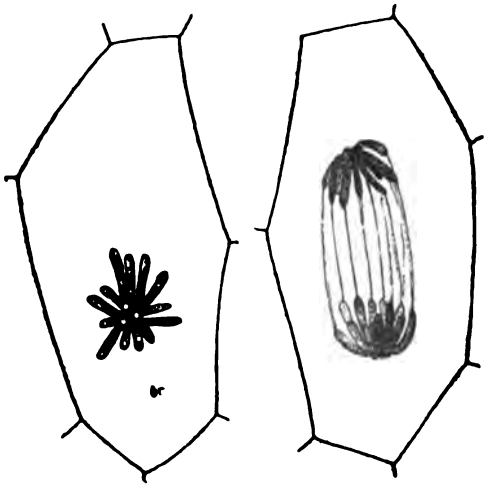


Fig. 411.

Karyokinesis in sporophyte cells of podophyllum (twice the number of chromosomes here that are found in the dividing spore mother cells).

at any point in the life cycle of plants, the number would thus become infinitely large. A reduction, however, does take place.

This usually occurs, either in the mother cell of the spores or in the divisions of its nucleus, at the time the spores are formed. In the mother cells a sort of pseudo-reduction is effected by the chromatin band separating into one half the usual number of nuclear segments. So that in lilium during the first division of the nucleus of the mother cell the chromatin band divides into twelve segments, instead of twenty-four as it has done throughout the sporophyte stage. So in podophyllum during the first division in the mother cell it separates into eight instead of into sixteen. Whether a qualitative reduction by transverse division of the spirem band, unaccompanied by a longitudinal splitting, takes place during the first or second karyokinesis is still in doubt. Qualitative reduction does take place in some plants according to Beliaieff and others. Recently the author has found that it takes place in Trillium grandiflorum during the second karyokinesis, and in Arisaema triphyllum the chromosomes divide both transversely and longitudinally during the first karyokinesis forming four chromosomes, and a qualitative reduction takes place here.

683. Significance of karyokinesis and reduction.—The precision with which the chromatin substance of the nucleus is divided, when in the spirem stage, and later the halves of the chromosomes are distributed to the daughter nuclei, has led to the belief that this substance bears the hereditary qualities of the organism, and that these qualities are thus transmitted with certainty to the offspring. In reduction not only is the original number of chromosomes restored, it is believed by some that there is also a qualitative reduction of the chromatin, i.e. that each of the four spores possesses different qualitative elements of the chromatin as a result of the reducing division of the nucleus during their formation.

The increase in number of chromosomes in the nucleus occurs with the beginning of the sporophyte, and the numerical reduction occurs at the beginning of the gametophyte stage. The full import of karyokinesis and reduction is perhaps not yet known, but there is little doubt that a profound significance is to be attached to these interesting phenomena in plant life.

684. The gametophyte may develop directly from the tissue of the sporophyte.—If portions of the sporophyte of certain of the mosses, as sections of a growing seta, or of the growing capsule, be placed on a moist substratum, under favorable conditions some of the external cells will grow directly into protonemal threads. In some of the ferns, as in the sensitive fern (onoclea), when the fertile leaves are expanding into the sterile ones, protonemal outgrowths occur among the aborted sporangia on the leaves of the sporophyte. Similar rudimentary protonemal growths sometimes occur on the leaves of the common brake (pteris) among the sporangia, and some of the rudimentary sporangia become changed into the protonema. In some other ferns, as in asplenium (A. filix-fœmina, var. clarissima), prothallia are borne among the aborted sporangia, which bear antheridia and archegonia. In these cases the gametophyte develops from the tissue of the sporophyte without the intervention or necessity of the spores. This is *apospory*.

685. The sporophyte may develop directly from the tissue of the gametophyte.—In some of the ferns, Pteris cretica for example, the embryo fern sporophyte arises directly from the tissue of the prothallium, without the intervention of sexual organs, and in some cases no sexual organs are developed on such prothallia. Sexual organs, then, and the fusion of the spermatozoid and egg nucleus are not here necessary for the development of the sporophyte. This is *apogamy*. Apogamy occurs in some other species of ferns, and in other groups of plants as well, though it is in general a rare occurrence except in certain species, where it may be the general rule.

Fig. 412.
Apogamy in Pteris cretica.

686. Types of nuclear division.—The nuclear figures in the vegetative cells are usually different from those in the spore mother cells. In the spore mother cells there are two types of nuclear division. (1) The first division in the mother cell is called *heterotypic*. The early stages of this division usually extend over a longer period than the second, and the figures are more complex. Before the chromosomes arrive at the nuclear plate they are often in the form of rings, or tetrads, or in the form of X, V, or Y, and the number is usually one half the number in the preceding cells of the sporophyte. (2) The *homotypic* division immediately follows the heterotypic and the figures are simpler, often the chromosomes being of a hook form, or sometimes much stouter than in the heterotypic division. In the vegetative cells (sometimes called somatic cells, or body cells in contrast with reproductive cells) there is another type, called by some the *vegetative type*. The chromosomes here are often in the form of the letter U, and the figures are much simpler than in the heterotypic division. In the somatic cells of the sporophyte, as stated above, the number of chromosomes is double that found in the heterotypic and homotypic divisions of the mother cells and in the somatic cells of the gametophyte, Fig. 411 represents a late stage in the division of somatic cells in the sporophyte of podophyllum. The root tips of various plants as the onion, lily, etc., are excellent places in which to study nuclear division in the somatic cells of the sporophyte.

687. Comparison with animals.—In animals there does not seem to be anything which corresponds with the gametophyte of plants unless the sperm cells and eggs themselves represent it. Heterotypic and homotypic division with the accompanying reduction of the number of the chromosomes takes place in animals usually in the mother cells of the sperms and eggs. At the time of fertilization the number of chromosomes is doubled, so that all the somatic cells (except in rare instances) from the fertilized egg to the mother cells of sperms and eggs have the doubled number of chromosomes. Reduction, therefore, takes place in animals just prior to the formation of the gametes, while

in plants it takes place just prior to the formation of the gametophytes.

688. Perhaps there is not a fundamental difference between gametophyte and sporophyte.—This development of sporophyte, or leafy-stemmed plant of the fern (parag. 685), from the tissue of the gametophyte is taken by some to indicate that there is not such a great difference between the gametophyte and sporophyte of plants as others contend. In accordance with this view it has been suggested that the leafy-stemmed moss plant, as well as the leafy stem of the liverworts, is homologous with the sporophyte or leafy stem of the fern plant; that it arises by budding from the protonema; and that the sexual organs are borne then on the sporophyte.

PART III.

PLANT MEMBERS IN RELATION TO ENVIRONMENT.

CHAPTER XXXVIII.

THE ORGANIZATION OF THE PLANT.

I. Organization of Plant Members.*

689. It is now generally conceded that the earliest plants to appear in the world were very simple in form and structure. Perhaps, the earliest were mere bits of naked protoplasm, not

* **Suggestions to the teacher.**—In the study of the flowering plants in the secondary school and in elementary courses three general topics are suggested. 1st, the study of the form and members of the plant and their arrangement, as in Chapters XXXVIII–XLV. 2d, the study of a few plants representative of the more important families, in order that the members of the plant, as studied under the first topic, may be seen in correlation with the plant as a whole in a number of different types; also to be able to recognize certain family likenesses or resemblances (example, to recognize plants of the lily type, the ament type, the mustard type, the rose type, labiate type, composite type, etc.), as in Chapters LVIII–LXV. 3d, the study of plants in their relation to environment, as in Chapters XLVI–LVII. The first and second topics can be conducted consecutively in the class-room and laboratory. The third topic can be studied at opportune times during the progress of topics 1 and 2. For example, while studying topic 1 excursions can be made to study winter conditions of buds, shoots, etc., if in winter period, or the relations of leaves, etc., to environment, if in the growing period. While studying topic 2 excursions can be made to study flower relations, and also vegetation relations (formations, etc.) to environment (see Chapter LVII). It is believed that a study of these three general topics is of much more value to the beginning student than the ordinary plant analysis and determination of species.

essentially different from early animal life. The simplest ones which are clearly recognized as plants are found among the lower algæ and fungi. These are single cells of very minute size, roundish, oval, or oblong, existing during their growing period in water or in a very moist substratum or atmosphere. Examples are found in the red snow plant (*Sphærella nivalis*), the Pleurococcus, the bacteria; and among small colonies of these simple organisms (Pandorina) or the thread-like forms (Spirogyra, Œdogonium, etc.). It is evident that some of the life relations of such very simple organisms are very easily obtained—that is, the adjustment to environment is not difficult. All of the living substance is very closely surrounded by food material in solution. These food solutions are easily absorbed. Because of the minute size of the protoplasts and of the plant body, they do not have to solve problems of transport of food to distant parts of the body. When we pass to more bulky organisms consisting of large numbers of protoplasts closely compacted together, the problem of relation to environment and of food transport become felt; the larger the organism usually the greater are these problems. A point is soon reached at which there is a gain by a differentiation in the work of different protoplasts, some for absorption, some for conduction, some for the light relation, some for reproduction, and so on. There is also a gain in splitting the form of the plant body up into parts so that a larger surface is exposed to environment with an economy in the amount of building material required. In this differentiation of the plant body into parts, there are two general problems to be solved, and the plant to be successful in its struggle for existence must control its development in such a way as to preserve the balance between them. (1) A ready display of a large surface to environment for the purpose of acquiring food and the disposition of waste. (2) The protection of the plant from injuries incident to an austere environment.

It is evident with the great variety of conditions met with in different parts of the same locality or region, and in different parts of the globe, that the plant has had very complex problems

to meet and in the solution of them it has developed into a great variety of forms. It is also likely that different plants would in many cases meet these difficulties in different ways, sometimes with equal success, at other times with varied success. Just as different persons, given some one piece of work to do, are likely to employ different methods and reach results that are varied as to their value. While we cannot attribute consciousness or choice to plants in the sense in which we understand these qualities in higher animals, still there is something in their "constitution" or "character" whereby they respond in a different manner to the same influences of environment. This is, perhaps, imperceptible to us in the different individuals of the same species, but it is more marked in different species. Because of our ignorance of this occult power in the plant, we often speak of it as an "inherent" quality.

Perhaps the most striking examples one might use to illustrate the different line of organization among plants in two regions where the environment is very different are to be found in the adaptation of the cactus or the yucca to desert regions, and the oak or the cucurbits to the land conditions of our climate. The cactus with stem and leaf function combined in a massive trunk, or the yucca with bulky leaves expose little surface in comparison to the mass of substance, to the dry air. They have tissue for water storage and through their thick epidermis dole it out slowly since there is but little water to obtain from dry soil.

The cucurbits and the oak in their foliage leaves expose a very large surface in proportion to the mass of their substance, to an atmosphere not so severely dry as that of the desert, while the roots are able to obtain an abundant supply of water from the moist soil. The cactus and the yucca have differentiated their parts in a very different way from the oak or the cucurbits, in order to adapt themselves to the peculiar conditions of the environment.

When we say that certain plants have the power to adapt themselves to certain conditions of environment, we do not mean to say that if the cucurbits were transferred to the desert they would take on the form of the cactus or the yucca. They could do neither. They would perish, since the change would be too great for their organization. Nor do we mean, that, if the cactus or yucca were transferred from the desert to our climate, they would change into forms with thin foliage leaves. They could not. The fact is that they are enabled to live in our climate when we give them some care, but they show no signs of assuming characters like those of our vegetation

What we do mean is, that where the change is not too great nor too sudden, some of the plants become slightly modified. This would indicate that the process of organization and change of form is a very slow one, and is therefore a question of time—ages it may be—in which change in environment and adaptation in form and structure have gone on slowly hand in hand.

690. Members of the plant body.—The different parts into which the plant body has become differentiated are from one point of view, spoken of as members. It is evident that the simplest forms of life spoken of above do not have members. It is only when differentiation has reached the stage in which certain more or less prominent parts perform certain functions for the plant that members are recognized. In the algæ and fungi there is no differentiation into stem and leaf, though there is an approach to it in some of the higher forms. Where this simple plant body is flattened, as in the sea-wrack, or ulva, it is a *frond*. The Latin word for frond is *thallus*, and this name is applied to the plant body of all the lower plants, the algæ and fungi. The algæ and fungi together are sometimes called *thallophytes*, or *thallus plants*. The word thallus is also sometimes applied to the flattened body of the liverworts. In the foliose liverworts and mosses there is an axis with leaflike expansions. These are believed by some to represent true stems and leaves; by others to represent a flattened thallus in which the margins are deeply and regularly divided, or in which the expansion has only taken place at regular intervals.

In the higher plants there is usually great differentiation of the plant body, though in many forms, as in the duckweeds, it is in the form of a frond. While there is a great variety in the form and function of the members of the plant body, they are all reducible to a few fundamental members. Some reduce these forms to three, the *root*, *stem*, *leaf;* while others to two, the *root*, and *shoot*, which is perhaps the best primary subdivision, and the shoot is then divided into stem and leaf, the leaf being a lateral outgrowth of the stem, and can be indicated by the following diagram:

Plant body..... { Shoot... { Stem. / Leaf. } / Root. }

KINDS OF SHOOTS.

691. Since it is desirable to consider the shoot in its relation to environment, for convenience in discussion we may group shoots into four prominent kinds: (1) *Foliage shoots;* (2) *Shoots without foliage leaves;* (3) *Floral shoots;* (4) *Winter conditions of shoots and buds.* Topic (4) will be treated in Chapter XXXIX, section IV.

692. (1st) Foliage shoots.—Foliage shoots are either aerial, when their relation is to both light and air; or they are aquatic, when their relation is to both light and water. They bear green leaves, and whether in the air or water we see that light is one of the necessary relations for all. Naturally there are several ways in which a shoot may display its leaves to the light and air or water. Because of the great variety of conditions on the face of the earth and the multitudinous kinds of plants, there is the greatest diversity presented in the method of meeting these conditions. There is to be considered the problem of support to the shoot in the air, or in the water. The methods for solving this problem are fundamentally different in each case, because of the difference in the density of air and water, the latter being able to buoy up the plant to a great degree, particularly when the shoot is provided with air in its intercellular spaces or air cavities. In the solu-

Fig. 413.
Lupinus perennis. Foliage shoot and floral shoot.

tion of the problem in the relation of the shoot to aerial environment, stem and leaf have in most cases coöperated; * but in view of the great variety of stems and their modifications, as well as of leaves, it will be convenient to discuss them in separate chapters.

693. (2d) Shoots without foliage leaves.—These are subterranean or aerial. Nearly all subterranean shoots have also aerial shoots, the latter being for the display of foliage leaves (foliage shoots), and also for the display of flowers (flower shoots). The subterranean kinds bear scale leaves, i.e., the leaves not having a light relation are reduced in size, being small, and they lack chlorophyll. Examples are found in Solomon's seal, man-

Fig. 413*a*.
Burrowing type, the mandrake, a "rhizome."

drake (fig. 413*a*), etc. Here the scale leaves are on the bud at the end of the underground stem from which the foliage shoot arises. Aerial shoots which lack foliage leaves are the dodder, Indian pipe-plant, beech drops, etc. These plants are saprophytes or parasites (see Chapter IX). Deriving their carbohydrate food from other living plants, or from humus, they do not need green leaves. The leaves have, therefore, probably been reduced in size to mere scales, and accompanying this there has been a loss of the chlorophyll. Other interesting examples of aerial shoots without foliage leaves are the cacti where

* It is interesting to note that in some foliage shoots the stem is entirely subterranean. See discussion of the bracken fern and sensitive fern in Chapter XXXIX.

the stem has assumed the leaf function and the leaves have become reduced to mere spines. The various modifications which shoots have undergone accompanying a change in their leaf relation will be discussed under stems in Chapter XXXIX.

694. (3d) Floral shoots.—The floral shoot is the part of the plant bearing the flower. As interpreted here it may consist of but a single flower with its stalk, as in Trillium, mandrake, etc., or of the clusters of flowers on special parts of the stem, termed flower clusters, as the *catkin*, *raceme*, *spike*, *umbel*, *head*, etc. In the floral shoot as thus interpreted there are several peculiarities to observe which distinguish it from the foliage shoot and adapt it to its life relations.

The floral shoot in many respects is comparable to the foliage shoot, as seen from the following peculiarities:

(1) It usually possesses, beside the flowers, small green leaves which are in fact foliage though they are very much reduced in size, because the function of the shoot as a foliage shoot is subordinated to the function of the floral shoot. These small leaves on the floral shoot are termed *bracts*.

(2) It may be (*a*) unbranched, when it would consist of a single flower, or (*b*) branched, when there would be several to many flowers in the flower cluster.

(3) The flower bud has the same origin on the shoot as the leaf bud; it is either terminal or axillary, or both.

(4) The members of the flower belong to the leaf series, i.e., they are leaves, but usually different in color from foliage leaves, because of the different life relation which they have to perform. Evidence of this is seen in the transition of sepals, petals, stamens, or pistils, to foliage leaves in many flowers, as in the pond lily, the abnormal forms of trillium, and many monstrosities in other flowers (see Chapter XXXIV).

(5) The position of the members of the flower on its axis, though usually more crowded, in many cases follows the same plan as the leaves on the stem.

The various kinds of floral shoots or flower clusters will be discussed in Chapter XLII, on the Floral Shoot.

II. Organization of Plant Tissues.

695. A tissue is a group of cells of the same kind having a similar position and function. In large and bulky plants different kinds of tissue are necessary, not only because the work of the plant can be more economically performed by a division of labor, but also cells in the interior of the mass or at a distance from the source of the food could not be supplied with food and air unless there were specialized channels for conducting food and specialized tissue for support of the large plant body. In these two ways most of the higher plants differ from the simple ones. The tissues for conduction are sometimes called collectively the *mestome*, while tissues for mechanical support are called *stereome*. Division of labor has gone further also so that there are special tissues for absorption, assimilation, perception, reproduction, and the like. The tissues of plants are usually grouped into three systems: (1) The Fundamental System, (2) The Fibrovascular System, (3) The Epidermal System. Some of the principal tissues are as follows:

1. THE FUNDAMENTAL SYSTEM.

696. Parenchyma.—Tissue composed of thin-walled cells which in the normal state are living. Parenchyma forms the loose and spongy tissue in leaves, as well as the palisade tissue (see Chapter IV); the soft tissue in the cortex of root and stem (Fig. 414), as well as that of the pith, of the pith rays or medullary rays of the stem; and is mixed in with the other elements of the vascular bundle where it is spoken of as wood parenchyma and bast parenchyma; and it also includes the undifferentiated tissue (meristem) in the growing tips of roots and shoots; also the "intrafascicular" cambium (i.e., between the bundles, some also include the cambium within the bundle).

697. Collenchyma.—This is a strengthening tissue often found in the cortex of certain shoots. It also is composed of living cells. The cells are thickened at the angles, as in the tomato and many other herbs (fig. 414).

698. Sclerenchyma, or stone-tissue.—This is also a strengthening tissue and consists of cells which do not taper at the ends and the walls are evenly thickened, sometimes so thick that the inside (lumen) of the cell has nearly disappeared. Usually such cells contain no living contents at maturity. Sclerenchyma is very common in the hard parts of nuts, and underneath

the epidermis of stems and leaves of many plants, as in the underground stems of the bracken fern, the leaves of pines (fig. 415), etc.

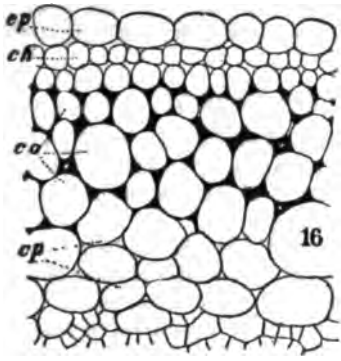


Fig. 414.

Transverse section of portion of tomato stem. *ep*, epidermis; *ch* chlorophyll-bearing cells; *co*, collenchyma; *cp*, parenchyma.

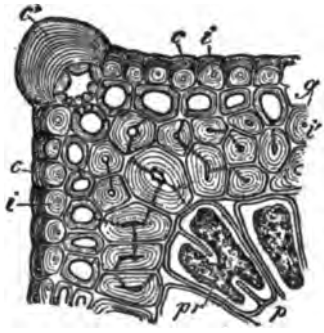


Fig. 415.

Margin of leaf of Pinus pinaster, transverse section. *c*, cuticularized layer of outer wall of epidermis; *i*, inner non-cuticularized layer; *c'*, thickened outer wall of marginal cell; *g*, *i'*, hypoderma of elongated sclerenchyma; *p*, chlorophyll-bearing parenchyma; *pr*, contracted protoplasmic contents. ×800. (After Sachs.)

699. Cork.—In many cases there is a development of "cork" tissue underneath the epidermis. Cork tissue is developed by repeated division of parenchyma cells in such a way that rows of parallel cells are formed toward the outside. These are in distinct layers, soon lose their protoplasm and die; there are no intercellular spaces and the cells are usually of regular shape and fit close to each other. In some plants the cell walls are thin (cork oak), while in others they are thickened (beech). The tissue giving rise to cork is called "cork cambium," or phellogen, and may occur in other parts of the plant. For example, where plants are wounded the living exposed parenchyma cells often change to cork cambium and develop a protective layer of cork. The walls of cork cells contain a substance termed *suberin*, which renders them nearly waterproof.

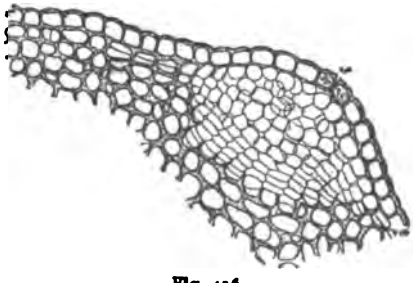


Fig. 416.

Section through a lenticel of Betula alba showing stoma at top, phellogen below producing rows of flattened cells, the cork. (After De Bary.)

700. Lenticels.—These are developed quite abundantly underneath stomates on the twigs of birch, cherry, beech, elder, etc. The phellogen underneath the stoma develops a cushion of cork which presses outward in the form of an elevation at the summit of which is the stoma (fig. 416). The lenticels can easily be seen.

2. THE FIBROVASCULAR SYSTEM.

701. Fibrous tissue.*—This consists of thick-walled cells, usually without living contents which are elongated and taper at the ends so that the cells, or fibers, overlap. It is common as one of the elements of the vascular bundles, as wood fibers and bast fibers.

702. Vascular tissue, or tracheary tissue.—This consists of the vessels or ducts, and tracheides, which are so characteristic of the vascular bundle (see Chapter V) and forms a conducting tissue for the flow of water. The vascular tissue contains spiral, annular, pitted, and scalariform vessels and tracheides according to the marking on the walls (figs. 58, 59). These are all without protoplasmic contents when mature. There are also thin-walled living cells intermingled called wood parenchyma. In the conifers (pines, etc.) the tracheary tissue is devoid of true vessels except a few spiral vessels in the young stage, while it is characterized by tracheides with peculiar markings. These marks on the tracheides are due to the "bordered" pits appearing as two concentric rings one within the other. These can be easily seen in a longitudinal section of wood of conifers.

703. Sieve tissue.—This consists of elongated tubular cells connected at the ends, the cross walls being perforated at the ends. These are in the phloem part of the bundle, and serve to conduct downwards the dissolved substances elaborated in the leaves.

704. Fascicular cambium.—This is the living, cell-producing tissue in the vascular bundle, which in the open bundle adds to the phloem on one side and the xylem on the other.

3. THE EPIDERMAL SYSTEM.

705. To the epidermal system belong the epidermis and the various outgrowths of its cells in the form of hairs, or *trichomes*, as well as the guard cells of the stomates, and probably some of the reproductive organs.

706. The epidermis.—The epidermis proper consists of a single layer of external cells originating from the outer layer of parenchyma cells at the growing apex of the stem or root. These cells undergo various modifications of form. In many cases they lose their protoplasmic contents. In many cases the outer wall becomes thickened, especially

* Some fibers occur also very frequently in the Fundamental System, forming bundle-sheaths, or strands of mechanical tissue in the cortex.

in plants growing in dry situations or where they are exposed to drying conditions. The epidermal cells generally become considerably flattened, and are usually covered with a more or less well developed water-proof cuticle, a continuous layer over the epidermis. In many plants the cuticle is covered with a waxy exudation in the form of a thin layer, or of rounded grains, or slender rods, or grains and needles in several layers. These waxy coverings are sometimes spoken of as "bloom" on leaves and fruit.

707. Trichomes.—Trichome is a general term including various hair-like outgrowths from the epidermis, as well as scales, prickles, etc. These include root hairs, rhizoids, simple or branched hairs, glandular hairs, glandular scales, etc. Glandular hairs are found on many plants, as tomato, verbena, primula, etc.; glandular scales on the hop; simple-celled hairs on the evening primrose, cabbage, etc.; many-celled hairs on the primrose, pumpkin; branched hairs on the shepherd's purse, mullein, etc., stellate hairs on some oak leaves.

For stomates see Chapter IV.

4. ORIGIN OF THE TISSUES.

708. Meristem tissue.—The various tissues consisting of cells of dissimilar form are derived from young growing tissue known as *meristem*. Meristem tissue consists of cells nearly alike in form, with thin cell walls and rich in protoplasm. It is situated at the growing regions of the plants. In the higher plants these regions in general are three in number, the stem and root apex, and the cambium cylinder beneath the cortex. Tissues produced from the stem and root apex are called *primary*, those from the cambium *secondary*. In most cases the main bulk of the plant is secondary tissue, while in the corn plant it is all primary.

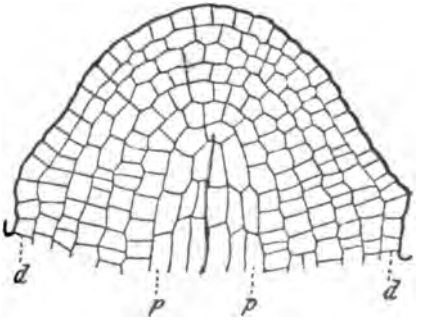


Fig. 417.
Section through growing point of stem. *d*, dermatogen; *p*, plerome; periblem between. (After De Bary.)

709. Origin of stem tissues.—Just back of the apical meristem in a longitudinal section of a growing point it can be seen that the cells are undergoing a change in form, and here are organized three formative regions. The outer layer of cells is called *dermatogen* (skin producer), because later it becomes the epidermis. The central group of elongating cells is the *plerome* (to fill). This later develops the *central cylinder*, or *stele*, as it is called

(fig. 417). Surrounding the plerome and filling the space between it and the dermatogen is the third formative tissue called the *periblem*, which later forms the cortex (bark or rind), and consists of parenchyma, collenchyma, sclerenchyma, or cork, etc., as the case may be. It should be understood that all these different forms and kinds of cells have been derived from meristem by gradual change. In the mature stems, therefore, there are three distinct regions, the central cylinder or stele, the cortex, and the epidermis.

710. Central cylinder or stele.—As the central cylinder is organised from the plerome it becomes differentiated into the vascular bundles, the pith, the pith rays (medullary rays) which radiate from the pith in the center between the bundles out to the cortex, and the pericycle, a layer of cells lying between the central cylinder and the cortex. The bundles then are farther organized into the xylem and phloem portions with their different elements, and the fascicular cambium (meristem) separating the xylem and phloem, as described in Chapter V. Such a bundle, where the xylem and phloem portions are separated by the cambium is called an open bundle (as in fig. 58). Where the phloem and xylem lie side by side in the same radius the bundle is a *collateral* one. Dicotyledons and conifers are characterized by open collateral bundles. This is why trees and many other

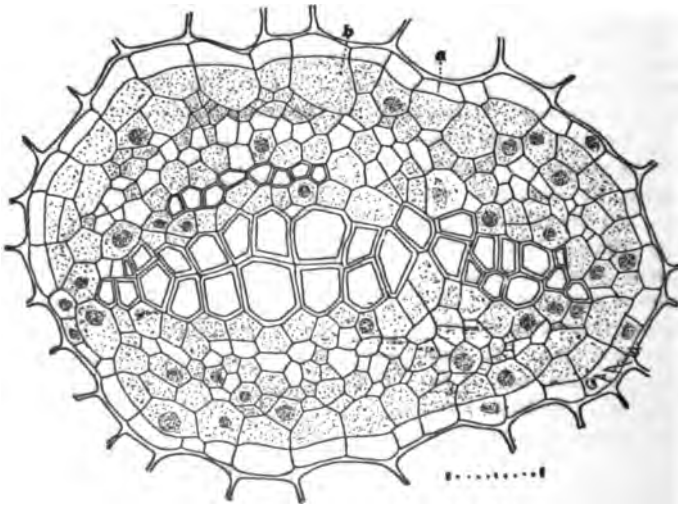


Fig. 418.

Concentric bundle from stem of Polypodium vulgare. Xylem in the center, surrounded by phloem and this by the endodermis. (From the author's Biology of Ferns.)

perennial plants continue to grow in diameter each year. The cambium in the open bundle forms new tissue each spring and summer, thus adding to the phloem on the outside and the xylem on the inside. In the spring and early summer the large vessels in the xylem predominate, while in late summer wood fibers and small vessels predominate and this part of the wood is firmer. Since the vascular bundles in the stem form a circle in the cylinder, this difference in the size of the spring and late summer wood produces the "annual" rings, so evident in the cross-section of a tree trunk. Branches originate at the surface involving epidermis, cortex, and the bundles.

In monocotyledonous plants (corn, palm, etc.) the bundles are not regularly arranged to form a hollow cylinder, but are irregularly situated through the stele. There is no meristem, or cambium, left between the xylem and phloem portions of the bundle and the bundle is thus *closed* (as in fig. 60), since it all passes over into permanent tissue. In most monocotyledons there is, therefore, practically no annual increase in diameter of the stem.

711. Ferns.—In the ferns and most of the Pteridophytes an apical meristem tissue is wanting, its place being taken by a single apical cell from the several sides of which cells are successively cut off, though Isoetes and many species of Lycopodium have an apical meristem group. In most of the Pteridophytes also the bundles are *concentric* instead of collateral. Fig. 418 represents one of the bundles from the stem of the polypody fern. The xylem is in the center, this surrounded by the phloem, the phloem by the phloem sheath, and this in turn by the endodermis, giving a concentric arrangement of the component tissues. A cross-section of the stem (fig. 419) shows two large areas of sclerenchyma, which gives the chief mechanical support, the bundles being comparatively weak.

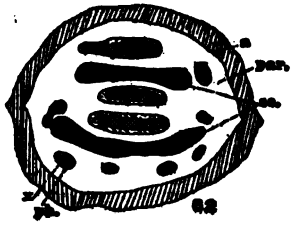


Fig. 419.
Section of stem (rhizome) of Pteris aquilina. *sc*, thick-walled sclerenchyma; *a*, thin-walled sclerenchyma; *par*, parenchyma.

712. Origin of root tissues.—A similar apical meristem exists in roots, but there is in addition a fourth region of formative tissue in front of the meristem called *calyptrogen* (fig. 420). This gives rise to the "root cap" which serves to protect the meristem. The vascular cylinder in roots is very different from that of the stem. There is a solid central cylinder in which the groups of xylem radiate from the center and groups of phloem alternate with them but do not extend so near the center (fig. 421). As the root ages, changes take place which obscure this arrangement more or less. Branches of the roots arise from the central cylinder. In fern roots the apical meristem is replaced by a single four-sided (tetrahedral)

apical cell, the root cap being cut off by successive divisions of the outer face, while the primary root tissues are derived from the three lateral faces.

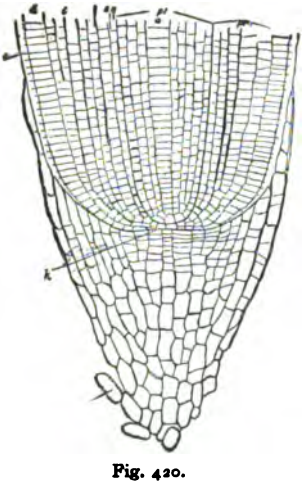


Fig. 420.

Median longitudinal section of the apex of a root of the barley, Hordeum vulgare. *k*, calyptrogen; *d*, dermatogen; *c*, its thickened wall; *pr*, periblem; *pl*, plerome; *en*, endodermis; *i*, intercellular air-space in process of formation; *a*, cell row destined to form a vessel; *r*, exfoliated cells of the root cap. (After Strasburger.)

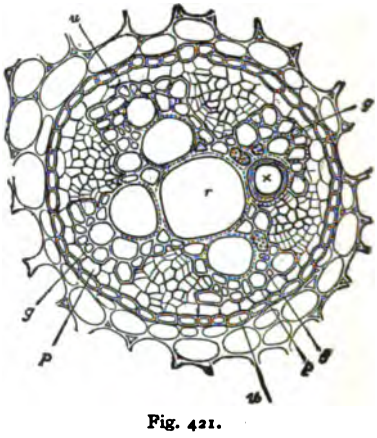


Fig. 421.

Cross-section of fibrovascular bundle in adventitious root of Ranunculus repens. *w*, pericycle; *g*, four radial plates of xylem; alternating with them are groups of phloem. This is a radial bundle. (After De Bary.)

Function of the root cap.—The root cap serves an important function in protecting the delicate meristem or cambium at the tip of the root. These cells are, of course, very thin-walled, and while there is not so much danger that they would be injured from dryness, since the soil is usually moist enough to prevent evaporation, they would be liable to injury from friction with the rough particles of soil. No similar cap is developed on the end of the stem, but the meristem here is protected by the overlapping bud-scales. One of the most striking illustrations of a root cap may be seen in the case of the Pandanus, or screw-pine, often grown in conservatories (see fig. 447). On the prop roots which have not yet reached the ground the root caps can readily be seen, since they are so large that they fit over the end of the root like a thimble on the finger.

713. Descriptive Classification of Tissues.

- **Epidermal System.....**
  - Epidermis.
  - Trichomes.
    - Simple hairs.
    - Many-celled hairs.
    - Branched hairs, often stellate.
    - Clustered, tufted hairs.
    - Glandular hairs.
    - Root hairs.
    - Prickles.
  - Guard-cells of stomates.
- **Fibrovascular System.....**
  - Xylem (wood).
    - Spiral vessels.
    - Pitted vessels.
    - Scalariform vessels.
    - Annular vessels.
    - Tracheides.
    - Wood fibers.
    - Wood parenchyma.
  - Cambium (fascicular).
  - Phloem (bast).
    - Sieve-tubes.
    - Bast fibers.
    - Companion cells.
    - Bast parenchyma.
- **Fundamental System.....**
  - Stem and root.
    - Cortex...
      - Cork.
      - Collenchyma.
      - Parenchyma.
      - Fibers.
      - Milk tissue.
    - Pith-ray..
      - Parenchyma.
      - Intrafascicular cambium.
    - Pith....
      - Parenchyma.
      - Sclerenchyma.
    - Bundle-sheath.
    - Endodermis.
  - Leaves.....
    - Palisade tissue.
    - Spongy parenchyma.
  - Reproductive Organs (mainly fundamental).

714. Physiological Classification of Tissues.

Formative Tissue.

Thin-walled cells composing the meristem, capable of division and from which other tissues are formed.

Protective Tissue.

Tegumentary System.—Epidermis, periderm, bark protecting the plant from external contact.

Mechanical System.—Bast tissue, bast-like tissue, collenchyma, sclerenchyma, afford protection against harmful bending, pulling, etc.

Nutritive Tissues.

Absorptive System.—Root hairs and cells, rhizoids, aerial root tissue, absorptive leaf glands, absorptive organs in seeds, haustoria of parasites, etc.

Assimilatory System.—Assimilating cells in leaf and stem.

Conductive System.—Sieve tissue, tracheary tissue, milk tissue, conducting parenchyma, etc.

Food-storing System.—Water reservoir, water tissue, slime tissue, fleshy roots and stems, endosperm and cotyledons, etc.

Aerating System.—Air spaces and tubes, special air tissue, air-seeking roots, stomates, lenticels, etc.

Secretory and Excretory System.—Water glands, digestive glands, resin glands, nectaries, tannin, pitch and oil receptacles, etc.

Apparatus and Tissues for Special Duties.

Holdfasts.

Tissues of movement, parachute hairs, floating tissue, hygroscopic tissue, living tissue.

For perceiving stimuli.

For conducting stimuli, etc.

CHAPTER XXXIX.

THE DIFFERENT TYPES OF STEMS. WINTER SHOOTS AND BUDS.

I. Erect Stems.

715. Columnar type.—The columnar type of stem may be simple or branched. When branching occurs the branches are usually small and in general subordinate to the main axis. The sunflower (Helianthus annuus) is an example. The foliage part is mainly simple. The main axis remains unbranched during the larger part of the growth period. The principal flowerhead terminates the stem. Short branches bearing small heads then arise in the axils of a few of the upper leaves. In dry, poor soil, or where other conditions are unfavorable, there may be only the single terminal flowerhead, when the stem is unbranched. The mullein is another columnar stem. The foliage part is rarely branched, though branches sometimes occur where the main axis has become injured or broken. The flower stem is terminal. The corn plant and the Easter lily are good illustrations also of the columnar stem.

Among trees the Lombardy poplar (Populus fastigiata) is an excellent example of the columnar type. Though this is profusely branched, the branches are quite slender and small in contrast with the main axis, unless by some injury or other cause two large axes may be developed. As the technical name indicates, the branching is fastigiate, i.e., the branches are crowded close together and closely surround the central axis. The royal palm and some of the tree ferns have columnar, simple stems,

but the large, wide-spreading leaves at the top of the stem give the plant anything but a cylindrical habit. Some cedars and arbor-vitæ are also columnar.

Fig. 422.
Cylindrical stem of mullein.

The advantages of the columnar habit of stem are three: (1) That the plant stands above other neighboring ones of equal foliage area and thus is enabled to obtain a more favorable light relation; (2) where large numbers of plants of the same species are growing close together, they can maintain practically the same habit as where growing alone; (3) the advantage gained by other types in their neighborhood in less shading than if the type were spreading. The cylindrical type can, therefore, grow between other types with less competition for existence.

716. The cone type.—This is well exampled in the larches, spruces, the gingko tree, some of the pines, cedars, and other gymnosperms. In the cone type, the main axis extends through the system of branches like a tall shaft, i.e., the trunk is *excurrent*. The lower branches are wide-spreading, and the branches become successively shorter, usually uniformly, as one ascends the stem. The branching is of two types: (1) the branches are in false whorls; (2) the branches

are distributed along the stem. To the first type belong the pines, Norway spruce, Douglas pruce, etc. *The white pine* is an exquisite example, and in young and middle-aged trees shows the style of branching to very good advantage. The branches are nearly horizontal, with a slight sigmoid graceful curve, while towards the top the branches are ascending. This direction of the branches is due to the light relation. The few whorls at the top are ascending because of the strong light from above. They soon become extended in a horizontal direction as the main source of light is shifting to the side by the shading of the top. The ascending direction first taken by the upper branches and their subsequent turning downward, while the ends often still have a slight ascending direction gives to the older branches their sigmoid curve.

Fig. 423.
Conical type of larch.

The young vernal shoots of the pines show some very interesting growth-movements. There are two growth periods: (1) the elongation of the shoot, and (2) the elongation of the leaves. The elongation of the shoot takes place first and is completed in about six weeks or two months' time. The direction of the shoot in the first period seems to be entirely influenced by geotropism. It grows directly upward and stands up as a very conspicuous object in strong contrast with the dark green foliage of the more or less horizontal shoots. When the second period of growth takes place, and the leaves elongate, the shoot bends downward and outward in a lateral direction.

The rate of growth of the pines can be very easily observed since each whorl of branches (between the whorls of long shoots

there are short shoots bearing the needle leaves), whether on the main axis or on the lateral branches, marks a year, the new branches arising each year at the end of the shoot of the previous year. The rate of growth is sometimes as high as twelve to twenty-four inches or more per year.

The *spruces* form a more perfect cone than the pines. The long branches are mostly in whorls, but often there are intermediate ones, though the rate of growth per year can usually be easily determined. In the *hemlock spruce*, the branching is distributed. The *larch* has a similar mode of branching, but it is deciduous, shedding its leaves in the autumn, and it has a tall, conical form.

It would seem that trees of the cone type possessed certain advantages in some latitudes or elevations over other trees. (1) A conical tree, like the spruces and larches and the pines, and hemlocks also, before they get very old, meets with less injury during high winds than trees of an oval or spreading type. The slender top of the tree where the force of the wind is greatest presents a small area to the wind, while the trunk and short slender branches yield without breaking. Perhaps this is one reason why trees of this type exist in more northern latitudes and at higher elevations in mountainous regions, and why the spruce type reaches a higher latitude and altitude even than the pines. (2) The form of the tree is such as to admit light to a large foliage area, even where the trees are growing near each other. The evergreen foliage, persistent for several years, on the wide-spreading lower branches, probably affords some protection to the trees since this cover would aid in maintaining a more equable temperature in the forest cover than if the trees were bare during the winter. (3) There is less danger of injury from the weight of snow since the greater load of snow would lie on the lower branches. The form of the branches also, especially in the spruces, permits them to bend downward without injury, and if necessary unload the snow if the load becomes too heavy.

717. The oval type.—This type is illustrated by the oak, chest-

nut, apple, etc. The trees are usually deciduous, i.e., cast their leaves with the approach of winter. The main axis is sometimes maintained, but more often disappears (trunk is *deliquescent*), because of the large branches which maintain an ascending direction, and thus lessen the importance of the central axis which is so marked in the cone type. Trees of this type, and in fact all deciduous trees, exhibit their character or habit to better advantage during the winter season when they are bare. Trees of this type are not so well adapted to conditions in the higher altitudes and latitudes as the cone type, for the reason given in the discussion of that type. The deciduous habit of the oaks, etc., enables them to withstand heavy winds far better than if they retained their foliage through the winter, even were the foliage of the needle kind and adapted to endure cold.

718. The deliquescent type.—The elm is a good illustration of this type. The main axes and the branches fork by a false dichotomy, so that a trunk is not developed except in the forest. The branches rise at a narrow angle, and high above diverge in the form of an arch. The chief foliage development is lofty and spreading.

Trees possess several advantages over vegetation less lofty. They may start their growth later, but in the end they outgrow the other kinds, shade the ground and drive out the sun-loving kinds.

II. Creeping, Climbing, and Floating Stems.

719. Prostrate type.—This type is illustrated by creeping or procumbent stems, as the strawberry, certain roses, of which a good type is one of the Japanese roses (Rosa wichuriana), which creeps very close to the ground, some of the raspberries, the curcubits like the squash, pumpkin, melons, etc. These often cover extensive areas by branching and reaching out radially on the ground or climbing over low objects. The cucurbits should perhaps be classed with the climbers, since they are capable of climbing where there are objects for support, but they are prostrate when grown in the field or where there are no ob-

jects high enough to climb upon. In the prostrate type, there is economy in stem building. The plants depend on the ground for support, and it is not necessary to build strong, woody trunks for the display of the foliage which would be necessary in the case of an erect plant with a foliage area as great as some of the

Fig. 424.
Prostrate type of the water fern (*marsilia*).

prostrate stems. This gain is offset, at least to a great extent, by the loss in ability to display a great amount of foliage, which can be done only on the upper side of the stem.

Other advantages gained by the prostrate stems are protection from wind, from cold in the more rigorous climates, and some propagate themselves by taking root here and there, as in certain roses, the strawberry plant, etc. Some plants have erect stems, and then send out runners below which take root and aid the plant in spreading and multiplying its numbers.

720. The decumbent type.—In this type the stem is first erect, but later bends down in the form of an arch, and strikes root where the tip touches the ground. Some of the raspberries and blackberries are of this type.

721. The climbing type.—The grapes, clematis, some roses, the ivies, trumpet creeper, the climbing bittersweet, etc., are climbing stems. Like the prostrate type, the climbers economize in the material for stem building. They climb over shrubs, up the trunks of trees and often reach to a great height and acquire the power of displaying a great amount of foliage by sending branches out on the limbs of the trees, sometimes developing an amount of foliage sufficient to cover and nearly smother the foliage of large trees; while the main stem of the vine may be not over two inches in diameter and the trunk of the supporting tree may be three feet in diameter.

722. Floating stems.—These are necessarily found in aquatic plants. The stems may be ascending or horizontal. The stems are usually not very large, nor very strong, since the water bears them up. The plants may grow in shallow water, or in water 10–12 feet or more deep, but the leaves are usually formed at or near the surface of the water in order to bring them near the light. Various species of Potamogeton, Myriophyllum, and other plants common along the shores of lakes, in ponds, sluggish streams, etc., are examples. Among the algæ are examples like Chara, Nitella, etc., in fresh water; Sargassum, Macrocystis, etc., in the ocean. In these plants, however, the plant body is a thallus, which is divided into stem-like (*caulidium*) and leaf-like (*phyllidium*) structures.

723. The burrowing type, or rhizomes.—These are horizontal, subterranean stems. The bracken fern, sensitive fern, the mandrake (see fig. 413*a*), Solomon's seal, Trillium, Dentaria, and the like, are examples. The subterranean habit affords them protection from the cold, the wind, and from injury by certain animals. Many of these stems act as reservoirs for the storage of food material to be used in the rapid growth of the short-lived aerial shoot. In the ferns mentioned, the subterranean is the only shoot, and this bears scale leaves which are devoid of chlorophyll, and foliage leaves which are larger, and the only member of the plant body which is aerial. The foliage leaf has assumed the function of the aerial shoot. The latter is

not necessary since flowers are not formed. The mandrake, Solomon's seal, Trillium, etc., have scale leaves on the fleshy underground stems, while foliage leaves are formed on the aerial stems, the latter also bearing the flowers. Some of the advantages of the rhizomes are protection from injury, food storage for the rapid development of the aerial shoot, and propagation.

Many of the grasses have subterranean stems which ramify for great distances and form a dense turf. For the display of foliage and for flower and seed production, aerial shoots are developed from these lateral upright branches.

III. Specialized Shoots and Shoots for Storage of Food.*

724. The bulb.—The bulb is in the form of a bud, but the scale leaves are large, thick, and fleshy, and contain stored in them food products manufactured in the green aerial leaves and transported to the underground bases of the leaves. Or when the bulb is aerial in its formation, it is developed as a short branch of the aerial stem from which the reserve food material is transported. Examples are found in many lilies, as Easter lily, Chinese lilies, onion, tulip, etc. The thick scale leaves are closely overlapped and surround the short stem within (also called a *tunicated* stem). In many lilies there is a sufficient

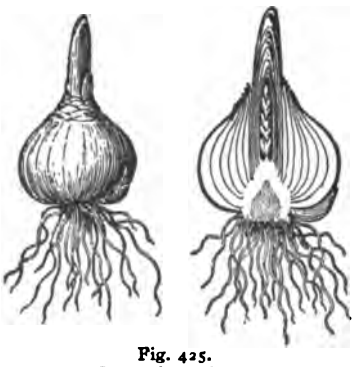


Fig. 425.
Bulb of hyacinth.

* Besides these specialized shoots for the storage of food, food-substances are stored in ordinary shoots. For example, in the trunks of many trees starch is stored. With the approach of cold weather the starch is converted into oil, in the spring it is converted into starch again, and later as the buds begin to grow the starch is converted into glucose to be used for food In many other trees, on the other hand, the starch changes to sugar on the approach of winter.

amount of food to supply the aerial stem for the development of flower and seed. There are roots, however, from the bulb and these acquire water for the aerial shoot, and when planted in soil additional food is obtained by them.

725. Corm.—A corm is a thick, short, fleshy, underground stem. A good example is found in the jack-in-the-pulpit (Arisæma).

Fig. 426.
Corm of Jack-in-the-pulpit.

726. Tubers. — These are thickened portions of the subterranean stems. The most generally known example is the potato tuber ("Irish" potato, not the sweet potato, which is a root). The "eyes" of the potato are buds on the stem from which the aerial shoots arise when the potato sprouts. The potato tuber is largely composed of starch which is used for food by the young sprouts.

726*a*. Phylloclades. — These are trees, shrubs, or herbs in which the leaves are reduced to mere bracts and stems, are not only green and function as leaves, but some or all of the branches are flattened and resemble leaves in form as in Phyllanthus, Ruscus, Semele, Asparagus, etc. The flowers are borne directly on these flattened axes. The prickly pear cactus (Opuntia) is also a phylloclade. Examples of phylloclades are often to be found in greenhouses.

727. Undifferentiated stems are found in such plants as the duckweed, or duckmeat (Lemna, Wolffia, etc. See Chapter III).

Fig. 427. Two-year-old twig of horse-chestnut, showing buds and leaf scars. (A twig with a terminal bud should have been selected for this figure.)

IV. Annual Growth and Winter Protection of Shoots and Buds.*

728. Winter conditions.†—While herbs are subjected only to the damp warm atmosphere of summer, woody plants are also exposed during the cold dry winter, and must protect themselves against such conditions. The air is dryer in winter than in summer; while at the same time root absorption is much retarded by the cold soil. Then, too, the osmotic activity of the dormant twig-cells being much reduced, the water-raising forces are at a minimum. It is easy to see, therefore, that a tree in winter is practically under desert conditions. Moreover, it has been found by various investigators, contrary to the general belief, that cold in freezing is only indirectly the cause of death. The real cause is the abstraction of water from the cell by the ice crystals forming in the intercellular spaces. Death ensues because the water content is reduced below the danger-point for that particular cell. It was formerly thought that on freezing, the cells in the tissue were ruptured. This is not so. Ice almost never forms within the cell, but in the spaces between. Freezing then is really a drying process, and dryness, not cold, causes death in winter. To protect themselves in winter, trees provide various waterproof coverings for the exposed surfaces and reduce the activity of the protoplasm so that it will be less easily harmed by the loss of water abstracted by the freezing process.

729. Protection of the twig.—Woody plants protect the living cells within the twigs by the production of a dull or rough corky bark, or by a

* This topic was prepared by Dr. K. M. Wiegand.

† See discussion of Tropophytes in Chapter XLVII.

thick glossy epidermis over the entire surface. At intervals occur small whitish specks called lenticels, which here perform nearly the same function as do stomates in the leaf.

730. Bark of trunk.—A similar service is performed by the bark for the main trunk and branches of the tree. To admit of growth in diameter the old bark is constantly being thrown off in strips, flakes, etc., and replaced by a new but larger cylinder of young bark. The external appearance thus produced enables experienced persons to recognize many kinds of trees by the trunk alone.

731. Leaf-scars and bundle-scars.—The presence of foliage leaves during the winter would greatly increase the transpiring surface without being of use to the plant; hence they are usually thrown off on the approach of winter. The scars left by the fallen leaves are termed leaf-scars. The small dots on the leaf-scars left by the vascular bundles which extended through the petiole into the twig are termed bundle-scars. Sometimes stipule-scars are left on each side of the leaf-scar by the fallen stipules.

732. Nodes and internodes.—The region upon a stem where a leaf is borne is termed a node. The space between two nodes is an internode.

733. Phyllotaxy.—Investigation of a horse-chestnut or willow twig will show that the leaf-scars occupy definite positions which are constant for each plant but different for the two species. The arrangement of the leaves on the stem in any plant is termed phyllotaxy. In the horse-chestnut we find two scars placed at the same node, but on opposite sides of the stem. Somewhat higher up we find two more similarly placed, but in a position perpendicular to that of the first pair. Such phyllotaxy is termed opposite. If in any plant several leaves occur at a node, the phyllotaxy is whorled. If but one at each node, as in the willow, the phyllotaxy is alternate. The opposite and alternate types are very commonly met with. Closer observation will show that in the willow, if a line be drawn connecting the successive leaf-scars, it will pass spirally up the twig until at length a scar is reached directly over the one taken as a starting-point. Such spiral arrangement always accompanies alternate phyllotaxy. The section of the spiral thus delineated is termed a cycle. We express the nature of the cycle by the fractions $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$, $\frac{5}{13}$, etc., in which the

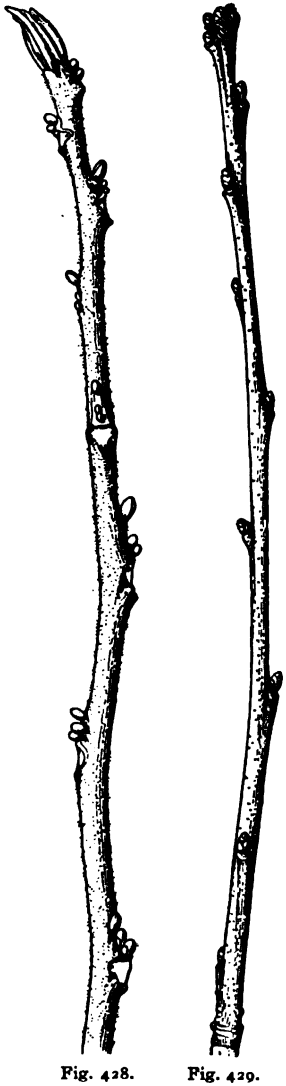


Fig. 428. Fig. 429.

Fig. 428.—Shoot of butternut showing leaf-scars, axillary buds, and adventitious buds (buds coming from above the axils).

Fig. 429.—Shoot and bud of white oak.

numerator denotes the number of turns around the stem in each cycle, and the denominator the number of leaf-scars in the same distance. In a general way we find in plants only such arrangements as are represented by the fractions given above. These fractions show the curious condition that the numerator and denominator of each is equal to the sum of the numerator or denominator of the two preceding fractions. Much speculation has been indulged in regarding the significance of these definite laws of leaf-arrangement. In part they may be due to the desire that each leaf receive the maximum amount of light. Only certain definite geometrical conditions will insure this. More likely it is due to the economy of space alotted to the leaf-fundaments in the bud. Here, again, geometrical laws govern this economy. The phyllotaxy is nearly constant for a given species.

734. Buds.—The growing point of the stem or branch together with its leaf or flower fundaments and protective structures is termed a bud. Winter buds on woody plants are terminal when inclosing the growing point of the main axis of the twig; lateral when the growing point is that of a branch of the main axis. Lateral buds are always axillary, i.e., situated on the upper angle between a leaf and the main axis.

735. Buds occupying special positions.—Several species of trees and shrubs produce more than one bud in each leaf-axil. The additional ones are termed accessory or supernumerary buds. These may

be lateral to one another or they may be superposed as in the walnut or butternut. In such cases some of the buds usually contain simply floral shoots and are termed flower-buds. In some species buds are frequently produced on the side of the branches and trunk at some distance from the leaf-axils, and entirely without regard for the latter; or more rarely may occur upon the root. Such buds are termed adventitious, and are the source of the feathery branchlets upon the trunks of the American elm.

736. Branching follows the phyllotaxy.—Since the lateral or branch-producing buds are always located in the axil of a leaf, the branches necessarily follow the same arrangement upon the main axis as do the leaves. Since, however, many of the axillary buds fail to develop, this arrangement may be more or less obscured.

737. Coverings of winter-buds.—These are of two sorts, hair and cork, or scales. Buds protected simply by dense hair or sunk in the cork of the twig are termed naked buds, and are comparatively rare. Most species protect their buds by the addition of an imbricated covering of closely appressed scales, the whole frequently being rendered still more water-proof by the excretion of resin between the scales or over the whole surface. The scales when studied carefully are found to be much reduced leaves or parts of leaves. In some cases they represent a modified whole leaf, when they are said to be laminar, or a leaf-petiole, when they are petiolar, or stipular, when they are much-specialized stipules of a leaf which itself is usually absent. The latter type is much the less common. The form of the bud, the nature and form of the scales, when combined with characters furnished by the leaf- and bundle-scars, enable one to recognize and classify the winter twigs of the various woody species.

738. Phyllotaxy of the bud-scales.—Since the bud-scales are leaves, they follow a definite phyllotaxy. This may or may not be the same as that of the foliage leaves. Twigs with opposite leaves have opposite bud-scales, or if with alternate leaves, then alternate bud-scales, but the fractions vary. If the scales are stipular, then there are of course two at each node.

739. Function of the bud-coverings.—It is popularly believed that the scales and hairy coverings serve to keep the bud warm. Research, however, shows this to be almost entirely erroneous, and that the thin bud coverings are entirely inadequate to keep out the cold of winter. They cannot keep the bud even a degree or two warmer than the outside air, except when the changes are very rapid. Experiment also shows that the modifying effect of the covering when the bud thaws out is so slight as to be almost negligible. Indeed, a thermometer bulb covered with scales taken from a horse-chestnut bud warmed up more rapidly than a naked one when exposed to sunshine. The wool in the horse-chestnut bud is not for the purpose of keeping it warm, but to protect the young shoot from too great transpiration after the bud opens the following spring. Research has also shown that such tempering of the heat conditions is not especially beneficial to the plant, as was once thought. Neither can we find the main function in the prevention of water from entering the bud. This might be accomplished in much simpler ways, even if we could demonstrate the desirability of keeping the water out at all.

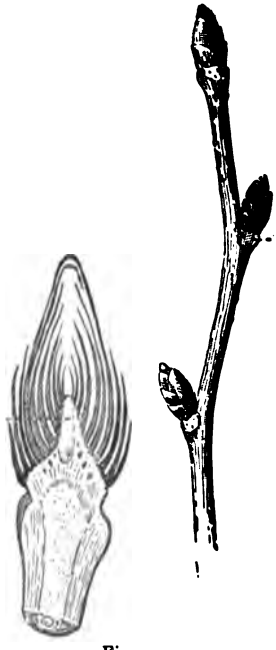


Fig. 430.
Bud of European elm in section, showing overlapping of scales.

The true functions of the bud-scales are two in number: Firstly, the prevention of too great loss of water from the young and delicate parts within; and secondly, the protection of these same parts from mechanical injury. Without some such protection the delicate young structures would be beaten off by the wind, or become the food for hungry birds during the long winter months.

740. Opening of the buds.—When the young shoot begins to grow in the spring, the bud-scales are forced apart or open of their own accord. During the young condition the shoot is very soft and brittle, and also possesses a very thin, little cutinized epidermis. In this condition it is especially liable to mechanical

Fig. 431.
Opening buds of hickory.

injury and to injury from drying out. We find, therefore, a tendency for the inner bud-scales to elongate during vernation, thus forming a tube around the delicate tissue much like the opening out of a telescope. The young leaves and internodes

themselves are often provided with a woody or hairy covering to retard transpiration. When the epidermis becomes more efficient the hairy covering often falls away.

In the case of naked buds protection is afforded in other ways: by the protection of hairy covering, by physiological adaptation of the tissue, or in many cases by the late appearance of the shoot in spring after the very dry April and May winds have ceased.

741. Bud-scars, and how to tell the age of the plant.—In general the bud-scales when they fall away in the spring leave scars termed scale-scars, and the whole aggregate of scale-scars makes up the bud-scar. The position of the buds of previous winters is, therefore, marked. It becomes an easy matter to determine the age of a branch, since all that is necessary is to follow back from one bud-scar to another, the portion of the stem between representing, except in rare cases, one year's growth.

A woody plant grows in height only by the formation of new sections of stem added to the apex or side of similar sections produced the previous season, never, as is commonly supposed, by the further elongation of the previous year's growth. Hence a branch once formed upon a tree is fixed as regards its distance from the ground. The apparent rise of the branches away from the ground in forest trees is an illusion caused by the dying away of the lower branches.

742. Definite and indefinite growth.—With the opening of the buds in spring, growth begins. In some cases, when all the members for the season were formed, but still minute, within the bud, such growth consists solely in the expansion of parts already formed; in others only a few members are thus present to expand, while new ones are produced by the growing point as the season progresses. In most cases growth is completed by the middle of July, soon after which buds are formed for next year's growth. Such a method of growth is termed definite.

In a few woody plants, as, for example, sumach, locust, and raspberry, growth continues until late in the autumn. In such cases the most recently formed nodes and internodes are unable to become sufficiently "hardened" before winter sets in, and

are killed back more or less. Next season's shoot is a branch from some axillary bud. Such growth is termed indefinite.

743. Structure of woody stems.—If we make a cross-section of a woody twig three general regions are presented to view. On the outside is the rather soft, often greenish "bark," so called, made up of sieve-tubes, ordinary parenchyma cells, and in many cases long fibrous cells composing the "fibrous bark." From a growing layer in this region, termed the phellogen, the true corky bark of the older trunk is formed.

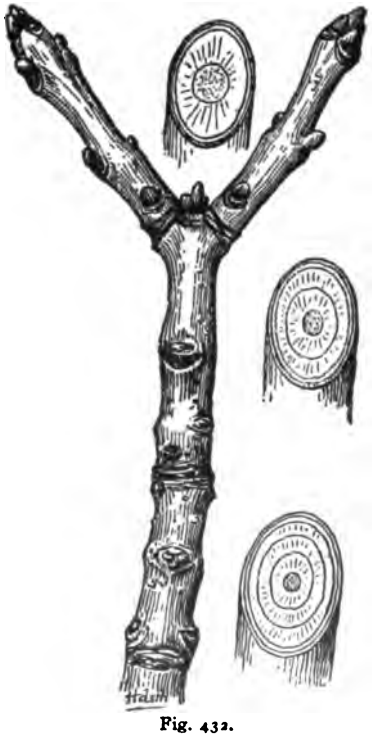


Fig. 432.
Three-year-old twig of the American ash, with sections of each year's growth showing annual rings.

Next within the bark we find the so-called "woody" portion of the twig. This is strong and resistant to both breaking and cutting. The microscope shows it to be composed of the ordinary already known woody elements,* wood-fibers, for strengthening purposes, pitted and spiral vessels as conducting tissue; and intermixed with these some living parenchyma cells. A cross-section of the stem also shows narrow radial lines through the wood. These are pith-rays, composed of vertical plates of living parenchyma cells. These cells, unlike the others in the wood, are elongated radially, not vertically. The height of the pith-rays as well as their thickness varies with the species studied. In the older trunk only the outer portion, a few inches in thickness, remains light-colored and fresh, and is called sap-wood. The inner wood is usually darker and harder, and is termed heart-wood. Living parenchyma cells, in general, are present only in the sap-wood, and in this almost solely the ascent of sap occurs. Dyestuffs and other substances are frequently deposited in the walls of the heart-wood.

The third region occupying the center of the twig is the pith. This

* Chapter V, and Organization of Tissues in Chapter XXXVIII.

is composed ordinarily of angular, little elongated, parenchyma cells, when mature mostly without cell-contents and filled with air. The pith region in different trees is quite diversified. It may be hollow, chambered, contain scattered thick-walled cells, have woody partitions, or rarely be entirely thick-walled.

The nature of the woody ring is rather perplexing at first; but its origin is simple. We may conceive that it has developed from a stem-type like the sunflower, in which the bundles, though separate, are connected by a continuous cambium ring. In the woody twigs the numerous bundles are closely packed together, and only separated by the primary pith-rays extending from the pith to the cortex. Other secondary pith-rays are produced within each bundle, but they usually extend only part way from the cortex to the pith. The wood represents the xylem of the bundle, and the sieve-tubes of the bark, the phloem.

744. Growth in thickness.—Although the year's growth does not increase in length after the first season has passed, it does increase in diameter very much. From the size of an ordinary little twig it may at length become a large tree trunk several feet in thickness. Only a portion of the first year's growth is produced by the growing point. All the rest is a product of the cambium, a cylinder of wood being added to the exterior of the old wood each season. The cambium, here, as in the sunflower, lies between the phloem and the xylem, forming a cylinder entirely around the stem. In spring, when active, it becomes soft and delicate, thus enabling one to easily strip off the bark from some trees, such as willow, etc., at that season.

745. Annual rings in woody stems.—The wood produced by the cambium each season is not homogeneous throughout, but is usually much denser toward the outer part of the yearly cylinder, wood-fibers here predominating. In the inner portion vessels predominate, giving a much more porous effect. The transition from one year's growth to another is very abrupt, giving rise to the appearance of rings in cross-section. Since ordinarily in temperate climates but one cylinder of wood is added each year, the number of rings will indicate the age of the trunk or branch. This is not absolutely accurate, since in some trees under certain conditions more than one ring may be produced in a summer. The porous part of the ring is often termed "spring wood," and the denser portion "fall wood," but since growth from the cambium ceases in most trees by the middle of July, "summer wood" would be more appropriate for the latter. It is mainly the alternation of the cylinders of the spring and summer wood that gives the characteristic grain to lumber. Pith-rays play an important part in wood graining only in a few woods, as, for instance, in quartered oak. The reason for the production of porous spring wood and dense summer wood is still one of the unsolved problems of botany.

CHAPTER XL.

FOLIAGE LEAVES.

I. General Form and Arrangement of Leaves.

746. Influence of foliage leaves on the form of the stem.— The marked effect which foliage has upon the aspect of the plant or upon the landscape is evident to all observers. Perhaps it is usual to look upon the stem as having been developed for the display of the foliage without taking into account the possibility that the foliage may have a great influence upon the form or habit of the stem. It is very evident, however, that the foliage exercises a great influence on the form of the stem. For example, as trees increase in age and size, the development of branches on the interior ceases and some of those already formed die, since the dense foliage on the periphery of the trees cuts off the necessary light stimulus. The tree, therefore, possesses fewer branches and a more open interior. In the forest also, the dense foliage above makes possible the shapely, clean timber trunks. Note certain trees where by accident, or by design, the terminal foliage-bearing branches have been removed that foliage-bearing branches may arise in the interior of the tree system.

Without foliage leaves the stems of green plants would develop a very different habit from what they do. This development could take place in three different directions under the influence of light: (1) The light stimulus would induce profuse branching, so that there would be many small branches. (2) The stem would develop fewer branches, but they would be flattened. (3) Massive trunks with but few or no branches. In fact, all

these forms are found in certain green stems which do not bear leaves. An example of the first is found in asparagus with its numerous crowded slender branches. But such forms in our climate are rare, since foliage leaves are more efficient. The second and third forms are found among cacti, which usually grow in dry regions under conditions which would be fatal to ordinary thin foliage leaves.

747. Relation of foliage leaves to the stem.—In the study of the position of the leaves on the stem we observe two important modes of distribution: (1) the distribution along the individual stem or branch which bears them, usually classed under the head of *Phyllotaxy;* (2) the distribution of the leaves with reference to the plant as a whole.

748. Phyllotaxy, or arrangement of leaves.—In examining buds on the winter shoots of woody plants, we cannot fail to be impressed with some peculiarities in the arrangement of these members on the stem of the plant.

In the horse-chestnut, as we have already observed, the leaves are in pairs, each one of the pair standing opposite its partner, while the pair just below or above stand across the stem at right angles to the position of the former pair. In other cases (the common bed-straw) the leaves are in whorls, that is, several stand at the same level on the axis, distributed around the stem. By far the larger number of plants have their leaves arranged alternately. A simple example of alternate leaves is presented by the elm, where the leaves stand successively on alternate sides of the stem, so that the distance from one leaf to the next, as one would measure around the stem, is exactly one half the distance around the stem. This arrangement is one half, or the angle of divergence of one leaf from the next is one half. In the case of the sedges the angle of divergence is less, that is one third.

By far the larger number of those plants which have the alternate arrangement have the leaves set at an angle of divergence represented by the fraction two fifths. Other angles of divergence have been discovered, and much stress has been laid on what is termed a law in the growth of the stem with reference to the position which the leaves occupy. Singularly by adding together the numerators and denominators of the last two fractions gives the next higher angle of divergence. Example: $\frac{1}{3}+\frac{2}{5}=\frac{3}{8}$; $\frac{2}{5}+\frac{3}{8}=\frac{5}{13}$; and so on. There are, however, numerous exceptions to this regular arrangement, which have caused some to question the importance of any theory like that of the "spiral theory" of growth propounded by Goethe and others of his time.

749. Adaptation in leaf arrangement.—As a result, however, of one arrangement or another we see a beautiful adaptation of the plant parts to environment, or the influence which environment, especially light, has had on the arrangement of the leaves and branches of the plant. Access to light and air are of the greatest importance to green plants, and one cannot fail to be profoundly impressed with the workings of the natural laws in obedience to which the great variety of plants have worked out this adaptation in manifold ways.

750. Distribution of leaves with reference to the entire plant.—In this case, as in the former, we recognize that it is primarily a light relation. As the plant becomes larger and more branched the lower and inner leaves disappear. The trees and shrubs have by far the larger number of leaves on the periphery of the branch system. A comparison of different kinds of trees in this respect shows, however, that there is great variation. Trees with dense foliage (elm, Norway maple, etc.) present numerous leaves on the periphery which admit but little light to the interior where leaves are very few or wanting. The sugar maple and red maple do not cast such a dense shade and there are more leaves in the interior. This is more marked in the silver maple, and still more so in the locust (Gleditschia tricanthos).

751. Color of foliage leaves.—The great majority of foliage leaves are green in color. This we have learned (Chapter VII) is due to the presence of a green pigment, chlorophyll, in the chloroplastids thickly scattered in the cells of the leaf. We have also learned that in the great majority of cases, the light stimulus is necessary for the production of chlorophyll green. There are many foliage leaves which possess other colors, as red (Rosa rubrifolia), purple (the purple barberry, hazel, beech, birch, etc.), yellow (the golden oak, elder, etc.); while many others have more or less deep tints of pink, red, purple, yellow, when young. All of these leaves, however, possess chlorophyll in addition to red, yellow, purple or other pigment. These other pigments are sometimes developed in great quantity in the cell-sap. They obscure the chlorophyll from view, but do not interfere seriously with the action of light and the function of chlorophyll, and perhaps in some cases serve as a screen to protect the protoplast.

752. Autumn colors.—Foliage leaves of many trees display in the autumn gorgeous colors. These colors are principally shades of red or yellow, and sometimes purple. The autumn color is more marked in some trees than in others. In the red maple, the red and scarlet oak, the sourwood, etc., red predominates, though sometimes yellow may be present with the red in a single leaf. Sugar maples, poplars, hickories, etc., are principally yellow in autumn. The sweet gum has a rich variety of color-red, purple, maroon, yellow; sometimes all these colors are present on the same tree

The red and purple colors are found suffused in the cell-sap of certain cells in the leaf much as we have found it in the cells of the red beet. The yellow color is chiefly due to the disappearance and degeneration of the chlorophyll while the leaf is in a moribund state. A similar phenomenon is seen in the yellowing of crops when the soil becomes too wet, or in the blanching of grass when covered with a board, or of celery as the earth is ridged up over the leaves in late summer and autumn. A number of different theories have been advanced to explain autumn coloring, i.e., the appearance of the red coloring-matter. It has been attributed to the approach of cold weather, and this has likely led to the erroneous belief on the part of some that it is caused by frost. It very often precedes frost. Some have attributed it to the action of the more oblique light rays during autumn, and still others to the diminishing water-supply with the approach of cool weather. The question is one which has not met as yet with a satisfactory solution, and is certainly a very obscure one. It is likely that the low temperature or the declining activities of the leaf affect certain organic substances in the leaf and give rise to the red color, and it is quite certain that in some years the display is more brilliant than in others. The color is more striking in some regions than in others and the different soil, as well as climate, has been supposed to have some influence. The North American forests are noted for the brilliant display of autumnal color. This is perhaps due to some extent to the great variety or number of species which display color. It would seem that there is some specific as well as individual peculiarities in certain trees. Some individuals, for example, exhibit brilliant colors every autumn, while others near of the same species are more subdued.

It has been shown by experiment that when sunlight passes through red colors the temperature is slightly increased, and it has been suggested that this may be of protection to the living substance which has ceased working and is in danger of injury from cold. There does not seem to be much ground for this suggestion, however. It certainly could not protect the protoplasm of the leaf at night when the cold is more intense, and during the day would only aggravate matters by supplying an increased amount of heat, since extremes of heat and cold in alternation are more harmful to plant life than uniform cold. Especially would this be the case in alpine climates where the alternation of heat and cold between day and night is extreme, and brilliancy of the colors of alpine plants is well known. It seems more reasonable to suppose that the red color acts as a screen, as the chlorophyll is disappearing, to protect from the injurious action of light, certain organic substances which are to be transferred back from the leaf to the stem for winter storage. So in the case of many stems in the spring or early summer when the young leaves often have a reddish color, it is likely that it acts as a screen to protect the living

substance from the strong light at that season of the year until the chlorophyll screen, which is weak in young leaves, becomes darker in color and more effective, when the red color often disappears.

753. Function of foliage leaves.—In general the function of the foliage leaf as an organ of the plant is fivefold (see Chapters IV, VII, VIII, XI), (1) that of carbon-dioxide assimilation or *photosynthesis*, (2) that of transpiration, (3) that of the synthesis of other organic compounds, (4) that of respiration, and (5) that of assimilation proper, or the making of new living substance. While none of these functions are solely carried on in the leaf, it is the chief seat of the first three of these processes, its form, position, and structure being especially adapted to the purpose. Assimilation proper, as well as respiration, probably take place equally in all growing or active parts.

754. Parts of the leaf.—All foliage leaves possess a *blade* or *lamina*, so called because of its *expanded* and *thin* character. The blade is the essential part. Many leaves, however, are provided with a stalk or *petiole* by which the blade is held out at a greater or lesser distance from the stem. Leaves with no petiole are *sessile*, the blade is attached by one end directly on the stem. In some cases the base of the blade is wrapped partly around the stem, or in others it extends entirely around the stem and is *perfoliate*. Besides, many leaves have short appendages, termed *stipules*, attached usually on opposite sides of the petiole at its junction with the stem. In some species of magnolia the stipules are so large that each one envelops the entire portion of the bud which has not yet opened. Many leaves possess outgrowths in the form of hairs, scales, etc. (See leaf protection.)

755. Simple leaves.—Simple leaves are those in which the blade is plane along the edge, not divided. The edge may be entire or indented (serrate) to a slight extent as in the elm. The form of the simple leaf varies greatly but is usually constant for a given species, or it may vary in shape in the same species on different parts of the plant. Some of the terms applied to the outline of the leaf are ovate, oval, elliptical, lanceolate, linear, needle-like, etc., but it is idle for one to waste time on

matters of minute detail in form until it becomes necessary for those in the future who pursue taxonomic work. It is evident that a simple leaf, except those of minute size, possesses advantages over a divided leaf in the amount of surface it exposes to the light. But in other respects it is at a disadvantage, especially as it increases in size, since it casts a deeper shade and does not admit of such a free circulation of air. It will be found, however, in our study of the relation of leaves to light and air that the balance between the leaf and its environment is obtained in the relation of the leaves to each other.

756. Venation of leaves.—A very prominent character of the leaf is its "venation." This is indicated by the presence of numerous " veins," indicated usually by narrow depressed lines on the upper surface, and by more or less distinct elevated lines on the under surface. There are two general types: (1) In the corn, Smilacina, Solomon's seal, etc., the veins extend lengthwise of the leaf and are nearly parallel. Such leaves are said to be *parallel-veined.* It is generally, though not always, a character of monocotyledenous plants. (2) In the elm, rose, hawthorn, maple, oak, etc., the veins are not all parallel. The larger ones either diverge from the base of the blade (palmate leaf, maple), or the mid-vein extends through the middle line of the leaf, while other prominent ones branch off from this and extend, nearly parallel, toward the edge of the leaf (pinnate venation). The smaller intermediate veins which are also very distinct extend irregularly and branch and anastomose in such a fashion as to give the figure of a net with very fine meshes. These are *netted-veined* leaves. These are characteristic of most of the dicotyledenous plants. It is evident from what has been said of the examples cited that there are two types of netted-veined leaves, the *palmate* and *pinnate.*

NOTE. As we have already learned in Chapter V the veins contain the vascular bundles of the leaf. Through them the water and food solutions are distributed to all parts of the leaf, and the return current of food material elaborated in the leaf moves back through the bast portion into the shoot. The veins also possess a small amount of mechanical tissue. This forms the framework of the leaf and aids in giving rigidity to the leaf and

in holding it in the expanded position. The mechanical tissue in the framework alone could not support the leaf. Turgescence of the mesophyll is needed in addition.

757. Cut or lobed leaves.—In many leaves, the indentations on the margin are few and deep. Such leaves present several lobes the proportionate size of which is dependent upon the depth of the indentation or "incision." Several of the maples, oaks, birches, the poison ivy, thistles, the dandelion, etc., have lobed leaves. Where the indentation reaches to or very near the midrib the leaf is said to be cut. A study of various leaves will show all gradations from simple leaves with plane edges to those which are cut or divided, as in compound leaves, and the lobes are often variously indented.

Fig. 433.
Lobed leaves of oak forming a mosaic.

758. Divided, or compound leaves.—The rose, sumac, elder, hickory, walnut, locust, pea, clover, American creeper, etc., are examples of divided or compound leaves. The former are pinnately compound, and the latter are palmately compound. The leaf of the honey-locust is twice pinnately compound or bipinnate, and some are three times pinnately compound.* It is

* Some of the different terms used to express the kinds of compound leaves are as follows:

Unifoliate (for a single leaflet, as in orange and lemon where the compound leaf is greatly reduced and consists of one pinna attached to the petiole by a joint). *Bifoliate* for one with two leaflets; *trifoliate* for one with three leaflets, as in the clover; *plurifoliate* for many leaflets. *Odd pinnate* for a pinnate leaf with one or more pairs of leaflets and one odd leaflet at the end.

evident that compound leaves are only extreme forms of lobed or cut leaves and that the form of all bears a definite relation to the primary venation. There has been a reduction of mesophyll and of the area of smaller venation.

759. These forms of leaves probably have some definite significance. It is not quite clear why they should have developed as they have; though it is possible to explain several important relations of these forms to their environment. (1) The reduction of the surface of the leaf, with the retention of the firmer portions, allows freer movement of the air and affords the leaf greater protection from injury during violent winds, just as the finely dissected leaves of some water-plants are less liable to injury from movement of the more dense medium in which they live. It is possible that here we may have an explanation of one of the factors involved in this reduction of leaf surface. (2) In trees with compound leaves, like the hickory, walnut, locust, ailanthus, etc., the midvein, and in the case of the Kentucky coffee-tree (Gymnocladus) the primary lateral veins also, serve in place of terminal branches of the stem. By the increase in the outline of the leaf and the reduction of its surface between the larger veins, the tree has attained the same leaf development that it would were the

Fig. 434.
Twice compound leaf. Leaflets arranged in one plane, but open spaces permit free circulation of air through the large leaf.

So leaves are *palmately bifoliate*, etc., *pinnately bifoliate*, etc. *Decompound* leaves are those where they are more than twice compound, as *ternately decompound* in the common meadow rue (Thalictrum).

Perfoliate leaves are seen in the bellwort (Uvularia), *connate perfoliate*, as in some of the honeysuckles where the bases of opposite leaves are joined together around the stem. *Equitant* leaves are found in the iris, where the leaves fit over one another at the base like a saddle.

larger veins replaced by stems bearing simple leaves. The tree as it is, however, has the advantage of being able to cast off for the winter period a layer of what otherwise would have been a portion of the stem system, to retain which through the winter would use more energy than with the present reduced stem system, and the stouter stem is less liable to dry out. In the case of herbaceous plants, in the case of plants like most of the ferns where the stem is on the underground rootstock (Pteris), or a very short erect stem, as in the Christmas fern, the leaf replaces the aerial stem, and the division (or branching, as it is sometimes styled) of the leaf corresponds to the branching of the stem. This is more marked in the gigantic exotics like Cibotium regale, and in the tree ferns which have quite tall trunks, the massive compound leaves replace branches. In the palms and cycads are similar examples. Those who choose to observe can doubtless find many examples close at hand. (3) While divided leaves have probably not been evolved in response to the light relation, still their relation in this respect is an important one, since if the leaf with its present size were entire, it would cast too dense a shade on other leaves below.

760. General structure of the leaf.—The general structure of the leaf has been already studied (see Chapters IV, V, VII). It is only necessary to recall the main points. The upper and lower surfaces of the leaf are provided with a layer of cells usually devoid of chlorophyll. The mesophyll of the leaf consists usually of a layer of palisade cells beneath the epidermis, and the remainder consists of loose parenchyma with large intercellular spaces. Through the mesophyll course the "veins," or fibro-vascular strands, consisting of the xylem and phloem portions and serving as conduits for water, salts, and foodstuffs. In the epidermis are the stomata, each one protected by the two guard cells. The guard cells as well as the mesophyll contain chlorophyll. The stomata and the communicating intercellular spaces furnish the avenues for the ingress and egress of gases, and for the escape of water vapor.

761. Protection of leaves.—There are many modifications of the general plan of structure in different leaves, many of them being adaptations for the protection of the leaf under adverse or trying conditions. Many leaves are also capable of assuming certain positions which afford them protection. The discussion of this subject may be presented under two general heads: Protective modifications; protective positions.

II. Protective Modification of Leaves.

762. General directions in which these modifications have taken place.—The usual type of foliage leaf selected is that of deciduous trees or shrubs or of our common herbs. Such a leaf is usually greatly expanded and thin in order to present as great a surface as possible in comparison with its mass, since the kind of work which the leaf has to do can be more effectually carried on when it possesses this form. This form of leaf is best adapted for work in regions where there is a medium amount of moisture such as exists in the temperate zones. But since there are very great variations in the climatic and soil conditions of these regions, and even greater changes in desert and arctic regions, the type of leaf described is unsuited for all. Its own life would be endangered, and it would also endanger the life of the plant. Modifications have therefore taken place to meet these conditions, or at least those plants whose leaves have become modified in those directions which are suited to the surrounding conditions have been able to persist. Excessive cold or heat, drought, winds, intense light, rain, etc., are some of the conditions which endanger leaves. The protective modifications of leaves may be grouped under four general heads: (1) Structural adaptations; (2) Protective covering; (3) Reduction of surface; (4) Elimination of the leaf through the complete assumption of the leaf function by the stem.

763. (1) **Structural adaptations.**—The general structure of the leaf presents certain features which are protective. The palisade layer of cells found usually beneath the upper epidermis forms a compact layer of long cells which not only acts as a light screen cutting off a certain amount of the light, since too intense light would be harmful; it also aids in lessening the loss of water from the upper surface, where radiation is greater. The stomata are usually on the under side of aerial leaves, and the mechanism which closes them when the leaf is losing too much water is protective. As a protection against intense light the number of palisade layers is sometimes increased or the

cells of this layer are narrow and long. This is often beautifully shown when comparing leaves of the same plant grown in strong light with those grown in the shade. The compass plant (Lactuca scariola) affords an interesting example. The leaves grown in the light are usually vertical, so that the light reaches both sides. Such leaves often have all of the mesophyll organized into palisade cells (fig. 435), while leaves grown in the deep shade may have no palisade cells.

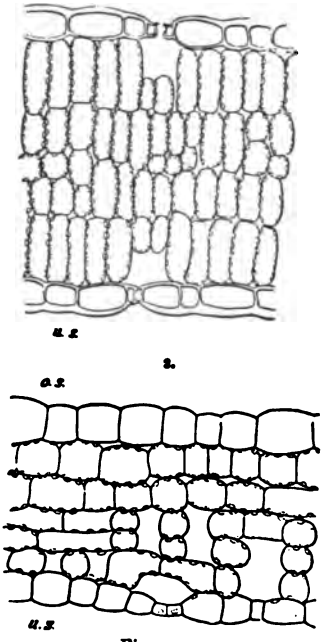


Fig. 435.
Structure of leaf of Lactuca scariola. Upper one grown in sunlight, palisade cells on both sides. Lower one grown in shade, no palisade tissue.

764. (2) **Protective covering.** —*Epidermis and cuticle.*—The walls of the epidermal cells are much thickened in some plants. Sometimes this thickening occurs in the outer wall, or both walls may be thickened. Variation in this respect as well as the extent of the thickening occur in different plants and are often correlated with the extremes of conditions which they serve to meet. The cuticle, a waxy exudation from the thick wall of the epidermis of many leaves, also serves as a protection against too great loss of water, or against the leaf becoming saturated with water during rains. The cabbage, carnation, etc., have a well-developed cuticle. The effect of the cuticle in shedding water can be nicely shown by spraying water on a cabbage leaf or by immersing it in water. Sunken stomata also retard the loss of water vapor.

Covers of hair or scales.—In many leaves certain of the cells of the epidermis grow out into the form of hairs or scales of various forms, and they serve a variety of purposes. When

the hairs form a felt-like covering as in the common mullein some antennarias, etc., they lessen the loss of water vapor because the air-currents close to the surface of the leaf are retarded. Spines (see the thistles, etc.) also afford a protection against certain animals.

765. (3) **Reduction of surface.**—Reduction of leaf surface is brought about in a variety of ways. There are two general modes: (1st) Reduction of surface along with reduction of mass; (2d) Reduction of surface inversely as the mass. Examples of the first mode are seen in the dissected leaves of many aquatic plants. In this finely dissected condition the mass of of the leaf substance is much reduced as well as the leaf surface, but the leaf is less liable to be injured by movement of the water. In addition it has already been pointed out that lobed and divided aerial leaves are much less liable to injury from violent movements of the air, than if a leaf with the same general outline were entire. The needle leaves of the conifers are also examples, and they show as well structural provisions for protection in the thick, hard cell-walls of the epidermis. To offset the reduced surface there are numerous crowded leaves. Reduction of surface inversely as the mass, i.e., the mass of the leaf may not be reduced at all, or it may be more or less increased. In other words, there is less leaf surface in proportion to the mass of leaf substance. It is probable in many cases, example: the crowded, overlapping small scale leaves of the juniper, arbor vitæ, cypress, cassiope, pyxidanthera, etc., that there has been a reduction in the size of the leaf, and at the same time an increase in thickness. This with the crowding together of the leaves and their thick cell-walls greatly lessens the radiation of moisture and heat, thus protecting the leaves both in dry and cold weather. The succulents, like "live-forever," have a small amount of surface in proportion to the mass of the leaf. In the yucca, though the leaves are often large, they are very thick and expose a comparatively small amount of surface to the dry air and intense sunlight of the desert regions. The epidermal covering is also hard and thick. In addition,

such leaves, as well as those of many succulents, are so thick they provide water storage sufficient for the plants, which radiate so slowly from their surface.

766. (4) **Elimination of the leaf.**—Perhaps the most striking illustration of the reduction of leaf surface is in those cases where

Fig. 436.
A "Phylloclade," leaves absent, stems broadened to function as leaves, on the edges numerous flowers are borne.

the leaf is either completely eliminated as in certain euphorbias, or in certain of the cacti where the leaves are thought to be reduced to spines. Whether the cactus spine belongs to the leaf series or not, the leaf as an organ for assimilation and transpiration has been completely eliminated and the same is true in the phylloclades. The leaf function has been assumed by the stem. The stem in this case contains all the chlorophyll; is bulky, and provides water storage.

III. Protective Positions.

767. In many cases the leaves are arranged either in relation to the stem, or to each other, or to the ground, in such a way as to give protection from too great radiation of heat or moisture. In the examples already cited the imbricated leaves of cassiope,

pyxidanthera, juniper, etc., come also under this head. In the junipers the leaves spread out in the summer, while in the winter they are closely overlapped. An interesting example of protective position is to be seen in the case of the leaves of the white pine. During quite cold winter weather the needles are appressed to the stem, and sometimes the trees present a striking appearance in contrast with the spreading position of the needles in summer. On windy days in winter, the needles turn with the wind and become rigid in that position so that they remain in a horizontal position for some time, often until the wind dies down, or until milder weather. The following day, should there be a cold strong wind from the opposite direction, the needles again assume a leeward direction. In quiet weather appressed to the stem and in the form of a brush there is less radiation of heat than if they diverged. In strong winds by turning in the leeward direction the wind is not driven between the needle bases and scales. Some plants, especially many of those in arctic and alpine regions, have very short stems and the leaves are developed near the ground, or the rock. Lying close on the ground they do not feel the full force of the drying winds, there is less radiation from them, and the radiation of heat from the ground protects them. Many plants exhibit movement in response to certain stimuli which place them in a position for protection. Some of these examples have been discussed under the head of irritability (see Chapter XIII). The night position of leaves and cotyledons presented by many plants, but especially by many of the Leguminosæ, is brought about by the removal of the light stimulus at evening. In many leaves, when the light influence is removed, the influence of growth turns the leaves downward, or the cotyledons of some plants upward. In this vertical position of the leaf-blade there is less radiation of heat during the cool night. The most striking cases of protection movements are seen in the sensitive plant. As we have seen, the leaves of mimosa close in a vertical position at midday if the light and heat are too strong. Excessive transpiration is thus prevented. At night the vertical

position prevents excessive radiation of heat. The vertical or profile position of the leaves of the compass plant already referred to not only lessens transpiration, but the intense heat and light of the midday sun is avoided. This profile position is characteristic of certain plants in the dry regions of Australia, and the topmost leaves of tropical forests.

IV. Relation of Leaves to Light.

768. It is very obvious from our study of the function of the foliage leaf that its most important relation to environment is that which brings it in touch with light and air. It is necessary that light penetrate the leaf tissue that the gases of the air and

Fig. 437
Mosaic form by trailing shoots of Panicum variegatum, "ribbon grass."

plant may readily diffuse and that water vapor may pass out of the leaf. The thin expanded leaf-blade is the most economical and efficient organ for leaf work. We have seen that leaves respond to light stimulus in such a way as to bring their upper sides usually to face the source of light, at right angles to it or nearly so (*heliotropism*, see Chapter XIII). How fully this is brought about depends on the kind of plant, as well as on other elements of the environment, for as we have seen in our study of leaf protection there is danger to some plants in any region,

and to other plants in certain regions that the intense light and heat may harm the protoplast, or the chlorophyll, or both.

The statement that leaves usually face the light at right angles is to be taken as a generalized one. The source of the strongest illumination varies on different days and again at different times of the day. On cloudy days the zenith is the source of strongest illumination. The horizontal position of a leaf, where there are no intercepting lateral or superior objects would receive its strongest light rays perpendicular to its surface. The fact is, however, that leaves on the same stem, because of taller or shorter adjacent stems, are so situated that the rays of greatest illuminating power are directed at some angle between the zenith and horizon. Many leaves, then, which may have their upper sides facing the general source of strongest illumination, no not necessarily face the sun, and they are thus protected from possible injury from intense light and heat because the direct rays of sunlight are for the most part oblique. This does not apply, of course, to those leaves which "follow the sun" during the day. Their specific constitution is such that intense illumination is beneficial.

The leaf is adjusted as well as may be in different species of varying constitution, and under different conditions, to a certain balance in its relation to the factors concerned. The problem then is to interpret from this point of view the positions and grouping of leaves. Because of the specific constitution of different plants, and because of a great variety of conditions in the environment, we see that it is a more or less complex question.

769. Day and night positions contrasted.—In many plants the day and night positions of the leaves are different. At night the leaves assume a position more or less vertical, known as the *profile* position. This is generally regarded as a protective position, since during the cool of the night the radiation of heat is less than if the leaf were in a vertical position. In many of these plants, however, the leaves in assuming the night position become closely appressed which would also lessen the radiation. This peculiarity of leaves is largely possessed by

the members of the family Leguminoseæ (clovers, peas, beans, etc.), and by the sensitive plants.* But it is also shared by some other plants as well (oxalis, for example). The leaves of these plants are usually provided with a mechanism which enables them to execute these movements with ease. There is a cushion (*pulvinus*) of tissue at the base of the petiole, and in the case of compound leaves, at the base of the pinnæ and pinnules which undergoes changes in turgor in its cells. The collapsing of the cells by loss of water into the intercellular spaces causes the leaf to droop. When the cells regain their turgor by the absorption of the water from the intercellular spaces the leaf is raised to the horizontal, or day position. The light stimulus induces turgor of the pulvinus, the disappearance of the stim-

Fig. 438.
Sunflower with young head turned toward morning sun.

ulus is accompanied by a loss of turgor. It is a remarkable fact that in some sensitive plants, intense light stimuli are alarm signals which result in the same movement as if the light stim-

* The most remarkable case is that of the "telegraph" plant (Desmodium gyrans). Aside from the day and night positions which the leaves assume, there is a pair of small lateral leaflets to each leaf which constantly execute a jerky motion, and swing around in a circle like the second hand of a watch.

ulus were entirely removed. As we know also contact or pressure stimulus, or jarring produces the same result in "sensitive" plants like mimosa, some species of rubus, etc. In many plants there is no well-developed pulvinus, and yet the leaves show similar movements in assuming the day and night positions. Examples are seen in the sunflower, and in the cotyledons of many plants. A little observation will enable any one interested to discover some of these plants.* In these cases the night position is due to epinastic growth, and while this influence is not removed during the day the light stimulus overcomes it and the leaf is raised to the day position.

770. Leaves which rotate with the sun.—During the growth period the leaves of the sunflower as well as the growing end

Fig. 439.
Same sunflower plant photographed just at sundown.

or the stem respond readily to the direct sunlight. The response is so complete that during sunny days the leaves toward the growing end of the stem are drawn close together in the form of a rosette and the entire rosette as well as the end of the

* Seedlings are usually very sensitive to light and are good objects to study.

stem are turned so that they face the sun directly. In the morning under the stimulus of the rising sun the rosette is formed and faces the east. All through the day, if the sun continues to shine, the leaves follow it, and at sundown the rosette faces squarely the western horizon. For a week or more the young sunflower head will also face the sun directly and follow it all day as surely as the rosette of leaves. At length, a little while before the flowers in the head blossom, the head ceases to turn,

Fig. 440.
Same plant a little older when the head does not turn, but the stem and leaves do.

but the rosette of leaves and the stem also, to some extent, continue to turn with the sun. When the leaves become mature they also cease to turn. This is well shown in all three photographs (figs. 438–439). The lower leaves on the stem being older have assumed the fixed horizontal position usually characteristic of the plant with cylindrical habit.

It is not true, as is commonly supposed, that the fully opened sunflower head turns with the sun. But I have observed young heads four or five inches in diameter rotate with the sun all day. This is because the growing end of the stem as well as the young head responds to the light stimulus. So there is some truth as well as a great deal of fiction in the popular belief that the sun-

flower head follows the sun. The young head will follow the sun all day even if all the leaves are cut off, and the growing stem will also if all the leaves as well as the flower head are cut away. Young seedlings will also turn even if the cotyledons and plumule are cut off.

This phenomenon of the rotation of leaves with the sun is much more general than one would infer, as may be seen from a little careful observation of rapidly growing plants on bright sunny days. In Alabama I have observed beautiful rosettes of *Cassia marilandica* rotate with the sun all day. The peculiarity is very striking in the cotton plant, especially when the rows extend north and south. In the forenoon or afternoon it is most striking as the entire row shows the leaves tilted up facing the sun. There are many of our weeds and common flowers of field and garden which show this rotation of the leaves. Some of these form rotating rosettes; while in others the leaves rotate independently as in the sweet clover.

771. Fixed position of old leaves.—In many of the cases cited in the preceding paragraph, the rotation of the leaf only occurs on sunny days. During cloudy days the leaves of the sunflower, for example, are in a nearly horizontal position, or the lower ones may be somewhat oblique, since the stronger illumination on such a plant would be the oblique rays rather than the zenith rays. As the leaves reach maturity also the epinasitic growth is equalized by hyponastic growth so that the growth movements bring the leaf to stand in a nearly horizontal position, or that position in which it receives the best illumination. In age, then, many leaves have a fixed position and this corresponds with the position assumed on cloudy days.

772. Position on horizontal stems.—On horizontal stems the leaves have a horizontal position, and if such a stem is stood in an erect position the appearance is very odd. If the leaf arises directly from the horizontal stem, its petiole will be twisted part way around in order to bring the face of the leaf uppermost. It is interesting to observe the different relation of stem, petiole and blade and the amount of twisting as the horizontal stem or

vine trails over irregularities in the surface, or climbs over and through other vegetation.

773. Position of leaflets on divided leaves.—An interesting comparison can be made with entire, lobed, divided and dissected leaves. The entire leaf usually lies in one plane, since usually the problem of adjustment is the same for the entire surface. So the lobes of a leaf usually lie all in the same plane as they would if the leaf were entire. We find the same is true usually of the compound leaf. It forms an incomplete mosaic. Some of the pieces having been removed allow much of the light to pass through to leaves beneath. Leaves, especially those of some size rarely lie in a flat plane. Some are more or less depressed. Some curve downward. Compound leaves often curve more or less and the leaflets often droop more or less in a graceful fashion. It is interesting, however, that these far-separated leaflets all lie in the same general plane. This is because the area of the leaf, if not too large, makes the problem of position with reference to light much the same as if the leaf were entire. The leaflets or divisions, though separated, are laminate, and they can work more efficiently facing the light. But suppose we extend our observation to the finely dissected capillary leaves of some of the parsley family (Umbelliferæ), or to the upper leaves of the fennel-leaved thoroughwort (Eupatorium fœniculaceum) among the aerial plants, and to Myriophyllum among the aquatic plants. The divisions are threadlike or cylindrical. One side of the leaflet is just as efficient when presented to the light as another. As a result the leaflets are not arranged in the same plane, but stand out in many directions.

Occasionally one finds a divided or compound leaf in such a position that one portion, because of being shaded above, receives the stronger light stimulus from the side, while the other portion is lighted from above. If this relation continues throughout the growth-period of the leaf the leaflets of one portion may lie in a different plane from those of the other portion. In such cases, some of the leaflets are permanently twisted to bring them into their proper light relation.

V. Leaf Patterns.

MOSAICS, OR CLOSE PATTERNS.

774. Where the leaves of a plant, or a portion of a plant, are approximate and arranged in the form of a pattern, the leaves fitting together to form a more or less even and continuous surface, such patterns are sometimes termed "mosaics," since the relation of leaves to one another is roughly like the relation of the pieces of a mosaic. A good illustration of a mosaic is presented by a greenhouse plant Fittonia (fig. 441). The stems

Fig. 441.

Fittonia showing leaves arranged to form compact mosaic. The netted venation of the leaf is very distinctly shown in this plant. (Photo by the Author.)

are prostrate and the erect branches quite short, but it may have quite a wide system by the spreading of the runners; the branches of such a length that the leaves borne near the tips all fit together forming a broad surface of leaves so closely fitted together often that the stems cannot be seen. The advantage of a mosaic over a separate disposition of leaves at somewhat different levels is that the leaves do not shade one another. Were all the light rays coming down at right angles to the leaves, there would not be any shading of the lower ones, but the oblique rays of light would be cut off from many of the leaves. In the case of a mosaic all the rays of light play upon all the leaves. Some of the mosaics which can be observed are as follows:

775. Rosette pattern.—The rosette pattern is presented by many plants with "radial" leaves, or leaves which arise in a cluster near the surface of the ground, and are thus more or less crowded in their arrangement on the stem. The pretty gloxinia often presents fine examples of a loose rosette. In the rosette pattern the petioles of the lower leaves are longer than the upper ones, and the blade is thus carried out beyond the inner leaves. The leaves being so crowded in their attachment to the stem lie very nearly in the same plane.

Fig. 442.
Rosette pattern of leaves.

776. Vines and climbers.—Some of the most extensive mosaic patterns are shown in creeping and climbing vines. A very common example is that of the ivies trained on the walls of buildings, covering in some instances many square yards of surface. Where the vines trail over the ground or clamber over other vegetation, it is interesting to observe the various patterns, and the distortion of petioles brought about by turning of the leaves. Of examples found in greenhouses, the Pellonia is excellent, and the trailing ribbon-grass often forms loose mosaics.

777. Branch patterns.—These patterns are very common. They are often formed in the woods on the ends of branches by the leaves adjusting themselves so as to largely avoid shading each other. Figure 443 illustrates one of them from a maple branch. It is interesting to note the way in which the leaves fit themselves in the pattern, how in some the petioles have elongated, while others have remained short. Of course, it

Fig. 443.
Spray of leaves of striped maple, showing different lengths of leafstalks.

Fig. 444.
Cedar of Lebanon, strong light only from one side of tree (Syria).

should be understood that the pattern is made during the growth of the leaves.

778. The tree pattern.—Mosaics are often formed by the exterior foliage on a tree, though they are rarely so regular as some of those mentioned above. Still it is common to see in some trees with drooping limbs like the elm, beautiful and large mosaics. The weeping elm sometimes forms a very close and quite even pattern over the entire outer surface. In most trees the leaf arrangement is not such as to form large patterns, but is more or less open. While the conifers do not form mosaics there are many interesting examples of grouping of foliage on branch systems into broadly expanded areas, as seen in the branches of white pine trees, especially in the edge of a wood, or as seen in the arbor vitæ.

OTHER PATTERNS.

779. Imbricate pattern of short stems.—This pattern is quite common, and differs from the rosette in that the leaves are distributed further apart on the stem so that the central ones are considerably higher up than in the mosaic. The lower petioles are longer, as in the rosette, so that the outer lower leaves extend further out. Some begonias show fine imbricate patterns.

Fig. 445.
Imbricate pattern of leaves; Begonia.

780. Spiral patterns.—They are very common on stems of the cylindrical type, which are unbranched, or but little branched. The sunflower, mullein, chrysanthemum, as it is grown in greenhouses, the Easter lily, etc., are examples. The spiral arrangement of the leaves provides that each successive leaf on the stem, as one ascends the stem, is a little to one side so that it does not cast shade on the

leaf just below. In some stems, according to the leaf arrangement (or phyllotaxy), one would pass several times around in ascending the stem before a leaf would be found directly above another, which would be such a distance below that it would not be shaded to an appreciable extent. Interesting observations can be made on different plants to work out the relation of distance of leaves on the stem to length of the upper and lower

Fig. 446.
Palm showing radiate arrangement of leaves and the petiole of the leaf functions as stem in lifting leaf to the light.

leaves; the number of vertical rows on the stem compared to the width of the leaves; and the relation of these facts to the problem of light supply. Related to the spiral pattern is that of erect stems with opposite leaves. Here each pair is set at right angles to the direction of the pair above or below.

781. Radiate pattern.—This pattern is present in many grasses and related plants with narrow leaves and short stems. The leaves are often very crowded at the base, but by radiating in all directions from the horizontal to the vertical, abundant ex-

posure to light is gained with little shading. The dragon tree screw-pine, and plants grown in greenhouses also illustrate this

Fig. 447.
Screw pine (Pandanus) showing prop roots and radiate pattern of leaves.

type. It is also shown in cycads, palms, and many ferns, although these have divided leaves.

782. Compass plants.—These plants with vertical leaf arrangement, and exposure of both surfaces to the lateral rays of light have been mentioned in other sections (Lactuca scariola).

783. Open patterns.—Open patterns are presented by divided or "branched" leaves. Where the leaves are very finely dissected, they may be clustered in great profusion and yet admit sufficient light for some depth below. Where the leaflets are broader, the leaves are likely to be fewer in number and so arranged as to admit light to a great depth so that successive leaves below on the same or adjacent stems may not be too much shaded. On such plants, often the leaves lying next the ground are entire or less divided.

CHAPTER XLI.

THE ROOT

I. Function of Roots.

784. The most obvious function of the roots of ordinary plants are two: 1st, To furnish anchorage and partial support, and 2d, absorption of liquid nutriment from the soil. The environmental relation of such roots, then, in broad terms, is with the soil. It is very clear that in some plants the root serves both functions, while in other plants the root may fulfil only one of these requirements.

The problems which the plant has to solve in working out these relations are:

(1) Permeation of the soil or substratum.

(2) Grappling the substratum.

(3) A congenial moisture or water relation.

(4) Distribution of roots for the purpose of reaching food-laden soil.

(5) Exposure of surface for absorption.

(6) The renewal of the delicate structures for absorption.

(7) Aid in preparation of food from raw material.

(8) The maintenance of the required balance between the environment as a whole and the increasing or changing requirements of the plant.

785. (1) **Permeation of the soil or substratum.**—The fundamental divergence of character in the environmental relations of root and stem are manifest as soon as they emerge from the germinating seed. Under the influence of the same stimulus (*gravity*) the root shows its geotropic character by growing down-

ward, while the geotropic character of the stem is shown in its upward growth.

The medium which the root has to penetrate offers considerable resistance, and the form of the root as well as its manner of growth is adapted to overcome this difficulty. The slender, conical, penetrating root-tip wedges its way between the minute particles of soil or into the minute crevices of the rock, while the nutation of the root enables it to search for the points of least resistance. The root-tips having penetrated the soil, the older portions of the root continue this wedge action by growth in diameter, though, of course, elongation of the old parts of the root does not take place. It is the widening growth of the tapering root that produces the wedge-like action. The crevices of the rock are sometimes broadened, but the resistance here is so great, the root is often greatly flattened out.

786. (2) **Grappling the substratum.**—The mere penetration of a single root into the soil gives it some hold on the soil and it offers some resistance to a "pull" since it has wedged its way in and the contact of soil particles offers resistance. The root-hairs formed on the first entering root growing laterally in great numbers and applying themselves very closely to the soil particles, increase greatly the hold of the plant on the soil, as one can readily see by pulling up a young seedling. Lateral roots are soon formed, and as these continue to extend and ramify in all directions, the hold is increased until in the case of some of the larger plants the resistance their hold would offer would equal many tons. Even in some of the smaller shrubs and herbs the resistance is considerable, as one can easily test by pulling with the hand. To obtain some idea of the amount of resistance the roots of these smaller plants offer, they can be tested by pulling with the ordinary spring scales.

787. (3) **A congenial moisture, or water relation.**—In general, the roots seek those portions of the soil provided with a modicum of moisture. Usually a suitable moisture condition is present in those portions of the soil containing the plant food. But if portions of the soil are too dry and very nearby other portions con-

taining moisture, the roots grow mainly into the moist substratum (*hydrotropism*). If the soil is too wet, the roots grow away from it to soil with less water, or in some cases will grow to and upon the surface of the soil.

The roots need *aeration*, and where the supply of water is too great, the air is shut out, and we know that corn, wheat, and many other plants become "sickly" in low and undrained soil in wet seasons. This can only be said in the case of our ordinary dry land plants, i.e., those that occupy an intermediate position between *water-loving* plants and *dry-conditioned* plants. This phase of the subject must be reserved for special treatment. (See Chapters XLVI, XLVII.)

788. (4) **Distribution of roots for the purpose of reaching food-laden soil.**—This is one of the essential relations of the root in the case of the land plant, and probably accounts for the very extensive ramification of the roots. To some extent it also explains the different root systems in some plants. The pines, spruces, etc., usually grow in regions where the soil is very shallow. The root system does not extend deeply into the soil. It spreads laterally and extends widely through the shallow surface soil and presents a very different aspect from the stem system in the air. The root-system of the broad-leaved trees usually extends more deeply into the soil, while of course, extending laterally to great distances. The hickory, walnut, etc., especially have strong tap roots which extend deeply into the soil, and the root system of such a tree is more comparable in aspect, if it were entirely uncovered, to the stem system in the air. The tap-root is more pronounced in some trees than in others. It may be that in the hickory and walnut the deep tap-root is important in supplying the tree with water in dry seasons, especially when growing on dry, gravelly soil which does not retain moisture on the surface nor hold it within two or three feet of the surface. Experiment has demonstrated, by pot culture of plants, that where soil rich in plant food lies adjacent to poor soil, no matter in what part of the pot the rich soil is, the greatest growth and branching of roots is in the rich soil.

789. (5) **Exposure of root surface for absorption.**—The principal part of root absorption takes place in the young root and the root hairs growing near the root-tip. The root-tips and root-hairs in their relation to the root systems on which they are borne are not to be compared morphologically with the leaves and stem system. But the root-tips and hairs are absorbing organs of the roots while the main root system supports them, brings them into relation with the soil and moisture, and conducts food and other substances to and from them. One of the important relations of the leaf is that of light, and since the source of light is restricted, i.e., it is not equally strong from all sides, an expanded and thin leaf-blade is more effective than an equal expenditure of plant material in the form of thread-like outgrowths. It is different, however, with the plant food dissolved in the soil water. It is equally accessible on all sides. A greater surface for absorption is exposed with the same expenditure of material by multiplication of the organs and a reduction in their size. Numerous delicate root-hairs present a greater absorbing surface than if the same amount of material were massed into leaflike expansions. There is another important advantage also. Its slender roots and thread-like root-hairs allow greater freedom of circulation of water, food solutions, and air than if the absorbing organs of the roots were broadly expanded.

790. (6) **The renewal of the delicate structures for absorption.**—The delicate root-hairs are easily injured. The thin cell-walls through which food solutions flow become more or less choked by the gradual deposit of substances in solution in the water, and continued growth of the root in diameter forms a firmer epidermis and cortex through which the solutions taken up by the root-hairs would pass with difficulty. For this reason new root-hairs are constantly being formed on the growing root-tip throughout the growing season, and in the case of perennial plants, through each season of their growth.

791. (7) **Aid in preparation of food from raw materials.**—For most plants the food obtained from the soil is already in solution in the soil water. But there are certain substances (examples, some

of the chemical compounds of potash, phosphoric acid, etc.) which are insoluble in water. Certain acids excreted by the roots aid in making these substances soluble (see Chapter III). In a number of plants the roots have become associated with fungus or bacterial organisms which assist in the manufacture of nitrogenous food substances, or even in the absorption of ordinary food solution from the soil, or in making use of the decaying humus of the forest (see Chapter IX).

792. (8) **The maintenance of the required balance between the environment and the increasing or changing requirements of the plant.**—In this matter the entire plant participates. Mention is made here only of the general relation which the root sustains to its own environment and the increased burden placed upon it by the shoot. The increase in the root system keeps pace with the increasing size of the stem system. The roots become stronger, their ramifications wider, and the number of absorbing rootlets more numerous. The observation is sometimes offered that the correlation between the root system of a plant, and the form of the stem system and position of the leaves, is of such a nature that plants with a tap-root system have their leaves so arranged as to shed the water to the center of the system, while plants with a fibrous root system have their leaves so arranged as to shed the water outward. In support of this attention is called to the radiate type of the leaf system of the dandelion, beet, etc. In the second place the imbricate type as manifested in broad-leaved trees, and in the overlapping branch systems of many pines, etc. One should note, however, that in the former class the leaves are often arranged to shed as much water outward as inward. As to the latter class, there is need of experiment to determine whether these empirical observations are correct, for the following reasons: 1st, Root and leaf distribution are governed by other and more important laws, the root being influenced by the location of food in the soil which usually forms a very thin stratum while the shoot and leaf is mainly influenced by light, and root distribution is much wider in a lateral direction than that of the branches. 2d, In light rains the leaf

surface holds back practically all the rain which is then evaporated into the air and lost to the root systems. 3d, In heavy and long-continued rains the water breaks through the leaf system to such an extent that roots under the tree would be as well supplied as those outside, and the ground outside being saturated anyway, the roots do not need the small additional water which may have been shed outward. 4th, It is the habit of plants where left undisturbed (except in rare cases), to grow in more or less dense formations or societies. Here there is no opportunity for any appreciable centrifugal distribution of rainfall and yet the root distribution is practically the same, except that the root systems of adjacent plants are interlaced.

II. Kinds of Roots.

793. The root system.—From the foregoing, it will be understood that the roots of a plant taken together form the *root system* of that plant. In soil roots in general we usually recognize two kinds of root systems.

794. The fibrous-root system.—Roots which are composed of numerous slender branching roots resembling "fibers," are termed *fibrous*, or the plant is said to have a *fibrous-root system.* The bean, corn, most grasses, and many other plants have fibrous-root systems.

795. The tap-root system.—Plants with a recognizable central shaft-like root, more or less thickened and considerably stouter than the lateral roots, are said to have *tap* roots, or they have a *tap-root system.* The dandelion, beet, carrot (see crown tuber) are examples. The hickory, walnut, and some other trees have very prominent tap-roots when young. The tap-root is maintained in old age, but the lateral roots often become finally as large as the tap-root. Besides tap-roots and fibrous-roots, which include the larger number, several other kinds of roots are to be enumerated.

796. Aerial roots.—Aerial roots are most abundantly developed in certain tropical plants, especially in the orchids and aroids. Many examples of these plants are grown in conserva-

tories. The amount of moisture is so great in these tropical regions that the roots are abundantly supplied without the soil relation. Certain of the roots hang free in the air and are provided with a special sheath of spongy tissue called the *velamen*, through which moisture is absorbed from the air. Other roots attach themselves to the trunk or branches of the tree on which the orchid is growing, and furnish the support to the *epiphyte*, as such plants are often called. Among the tangle of these clinging roots falling leaves are caught. Here they decay and nourishing roots grow from the clinging roots into this mass of decaying leaves and supply some of the plant food. Aerial roots sometimes possess chlorophyll.

There are a number of plants, however, in temperate regions which have aerial roots. These are chiefly used to give the stem support as it climbs on trees or on walls. They are sometimes called clinging roots. A common example is the climbing poison ivy (Rhus radicans), the trumpet creeper, etc. Such aerial roots are called *adventitious* roots.

797. Bracing roots, or prop roots.—These are developed in a great variety of plants and serve to brace or prop the plant where the fibrous-root system is insufficient to support the heavy shoot system, or the shoot system branches so widely props are needed to hold up the branches. In the common Indian corn several whorls of bracing roots arise from the nodes near the ground and extend outward and downward to the ground, though the upper whorls do not always succeed in reaching the ground. The screw-pine so common in greenhouses affords an excellent example of prop roots. The roots are quite large, and long before the root reaches the soil the

Fig. 448.
Bracing roots of Indian corn.

large root-cap is evident. The banyan tree of India is a classic example of prop roots for supporting the wide-reaching branches. The mangrove in our own subtropical forests of Florida is a nearer example.

798. Buttresses are formed at the junction of the root and trunk, and therefore are part root and part stem. Splendid

Fig. 449.
Buttresses of silk-cotton tree, Nassau.

examples of buttresses are formed on the silk-cotton tree. They are sometimes formed on the elm and other trees in low swampy ground.

799. Fleshy roots, or root tubers.—These are enlargements of the root in the form of tubers, as in the sweet potato, the dahlia, etc. They are storage reservoirs for food. Portions of the roots become thick and fleshy and contain large quantities of sugar, as in the sweet potato, or of *inulin* (a carbohydrate) in the root-tubers of the dahlia and other composites.

800. Water roots and roots of water plants.—These are roots which are developed in the water, or in the soil. Water-roots are sometimes formed on land plants where the root comes in

contact with a body of water, or a stream. Water-roots usually possess no root-hairs, or but a few, as can be seen by comparing water-roots with soil-roots, or by comparing roots of plants grown in water cultures. The greater body of water in contact with the root and the more delicate epidermis of the root render less necessary the root-hairs. The duck-meats (Lemna) are good examples of plants having only water-roots. Other aquatic plants like the potamogetons, etc., have true roots which grow into the soil and serve to anchor the plant, but they are not developed as special organs of absorption, since the stem and leaves largely perform this function.

801. Holdfasts.—These are organs for anchorage which are not true roots. These are especially well developed in some of the algæ (Fucus, Laminaria, etc.). They are usually called *holdfasts*. The holdfasts of the larger algæ are mainly for anchoring the plant. They do not function as absorbing organs, and the structure is different from that of true roots.

802. Haustoria or suckers is a name applied to another kind of holdfast employed by parasitic plants. In the dodder the haustorium penetrates the tissue of the *host* (the plant on which the parasite grows), and besides furnishing a means of attachment, it serves as an absorbing organ by means of which the parasite absorbs food from its host. The parasitic fungi like the powdery mildews which grow on the surface of their hosts have simple haustoria which serve both as organs of attachment and absorption, while in the rusts which grow in the interior of their hosts the haustoria are merely absorbing organs.

803. Rootlets, or rhizoids.—Many of the algæ, liverworts and mosses have slender, hair-like organs of attachment and absorption. These plants do not have true roots. Because of the slender form and small size of these organs, they are called *rhizoids*, or *rootlets*. In form many of them resemble the root-hairs of higher plants.

CHAPTER XLII.

THE FLORAL SHOOT.

I. The Parts of the Flower.

THE portion of the stem on which the flowers are borne is the *flower* shoot or axis, or taken together with the flowers, it is known as the *Flower Cluster.*

804. The flower.—The flower is best understood by an examination, first of one of the types known as a "complete" flower, as in the buttercup, the spring beauty, the bloodroot, the apple, the rose, etc.

There are two sets of organs or members in the complete flower—(1) the floral envelope; (2) the essential or necessary members or organs.

The floral envelope when complete consists of—1st, an outer envelope, the *calyx*, made up of several leaflike structures (*sepals*), very often possessing chlorophyll, which envelop all the other parts of the flower when in bud; 2d, an inner envelope, the *corolla*, also made up of several leaflike parts (*petals*), usually bright colored and larger than the sepals. The outer and inner floral envelopes are usually in whorls (though in close spirals in many of the buttercup family, etc.), and for reasons discussed elsewhere (Chapter XXXIV) represent leaves. The essential or necessary members of the flower are also usually in whorls and likewise represent leaves, but only in rare cases is there any suggestion, either in their form or color, of a leaf relationship. These members are in two sets: (1) The outer, or *andrœcium*, consisting of a few or many parts (*stamens*); (2) the inner set, the *gynœcium*, consisting of a few or many parts (*carpels*).

805. Purpose of the flower.—While the ultimate purpose of all plants is the production of seed or its equivalent through which the plant gains distribution and perpetuation, the flower is the specialized part of the seed plant which utilizes the food and energies contributed by other members of the plant organization for the production of seed. In addition to this there are definite functions performed by the members of the flower, which come under the general head of plant work, or flower work.

806. The calyx, or the sepals.—These are chiefly protective, affording protection to the young stamens and carpels in the flower bud. Where the corolla is absent, sepals are usually present and then assume the function of the petals. In a few instances the calyx may possibly ultimately join in the formation of the fruit (examples: the butternut, walnut, hickory).

807. The corolla, or petals.—The petals are partly protective in the bud, but their chief function where well developed seems to be that of attracting insects, which through their visits to the flower aid in "*pollination*," especially "*cross pollination*."

808. The stamens.—The stamens (=microsporophylls) are flower organs for the production of *pollen*, or *pollen-spores* (=microspores). The *stalk* (not always present) is the *filament*, the *anther* is borne on the filament when the latter is present. The anther consists of the *anther sacs* or *pollen sacs* (microsporangium) containing the pollen-spores, and the *connective*, the sterile tissue lying between and supporting the anther sac. The stamens are usually separate, but sometimes they are united by their filaments, or by their anthers. When the pollen is ripe they open by slits or pores and the pollen is scattered; or in rarer cases the pollen mass (*pollinium*) is removed through the agency of insects (see Insect pollination, Chap. XLIII).

809. The pistil.—The pistil consists of the "*ovary*," the *style* (not always present), and the *stigma*. These are well shown in a *simple pistil*, common examples of which are found in the buttercup, marsh marigold, the pea, bean, etc. The simple pistil is equivalent to a *carpel* (=macrosporophyll), while the *compound pistil* consists of two or several carpels joined, as in

the toothwort, trillium, lily, etc. The *ovary* is the enlarged part which below is attached to the receptacle of the flower, and contains within the *ovules*. The *style*, when present, is a slender elongation of the upper end of the ovary. The *stigma* is supported on the end of the style when the latter is present. It is often on a capitate enlargement of the style or extends down one side, or when the style is absent it is usually seated directly on the upper end of the ovary. The stigmatic surface is glutinous or "sticky," and serves to hold the pollen-spores when they come in contact with it.

The *ovules* are within the ovary and are arranged in different ways in different plants. The pollen-grain (or better pollen-spore = microspore), after it has been transferred to the stigma, "germinates," and the pollen tube grows down through the tissue of the stigma and style, or courses down the stylar canal until it reaches the ovule. Here it usually enters the ovule (macrosporangium) at the *micropyle* (in some of the ament-bearing plants it enters at the *chalaza*), and the sperm-cells are emptied into the embryo sac in the interior of the ovule.

810. Fertilization.—One of the sperms unites with the egg in the embryo sac. This is *fertilization*, and from the fertilized egg the young embryo is formed still within the ovule. *Double fertilization*,—the other sperm-cell sometimes unites with one or both of the "polar" nuclei which have united to form the "definitive" or "endosperm" nucleus. As a result of fertilization, the embryo plant is formed within the ovule, the coats of which enlarge by growth forming the seed coats, and altogether forming the seed. (See Chapters XXXIV, XXXV, XXXVI.)

II. Kinds of Flowers.

811. Absence of certain flower parts.—The *complete* flower contains all the four series of parts. When any one of the series of parts is lacking, the flower is said to be *incomplete*. Where only one series of the floral envelopes is present the flowers are said to be *apetalous* (the petals are absent), examples: elm, buckwheat,

etc. Flowers which lack both floral envelopes are *naked*. When pistils are absent but stamens are present the flowers are *staminate*, whether floral envelopes are present or not; and so when stamens are absent and pistils pre ent the flower is *pistillate*. If both stamens and pistils are absent the flower is said to be *sterile* or *neutral* (snowball, marginal or showy flowers in hydrangea). Flowers with both stamens and pistils, whether or not they have floral envelopes, are *perfect* (or hermaphrodite), so if only one of these sets of *essential organs* of the flower is present the flower is *imperfect*, or *diclinous*. Sometimes the imperfect, or diclinous, flowers are on the same plant, and the plant is said to be *monœcious* (of one household). When staminate flowers are on certain individual plants, and the pistillate flowers of the same species are on other individuals, the plant is *diœcious* (or of two households). When some of the flowers of a plant are diclinous and others are perfect, they are said to be *polygamous*.

Many of these variations relating to the presence or absence of flower parts in one way or another contribute to the well-being of the plant. Some indicate a division of labor; thus in the neutral flowers of certain species of hydrangea or viburnum, the showy petals serve to attract insects which aid in the pollination of the fertile flowers. It must not be understood, however, that all variations in plants which results in new or different forms of flowers is for the good of the species. For example, under cultivation the flowers of viburnum and hydrangea sometimes are all neutral and showy. While such variations sometimes contribute to the happiness of man, the plant has lost the power of developing seed. In diclinous flowers cross pollination is necessitated.

812. Form of the flower.—The flower as a whole has *form*. This is so characteristic that in general all flowers of the different individuals of a species are of the same shape, though they may vary in size. In general, flowers of closely related plants of different species are of the same type as to form, so that often in the shape of the flower alone we can see the relationship of kind, though the form of the flower is not the most important nor always the sure index of kinship. Since many flowers resemble

certain familiar objects, names are often used which relate to these objects.

Flowers are said to be *regular*, or *irregular*. In a regular flower all of the parts of a set or series are of the same shape and size, while in irregular flowers the parts are of a different shape or size in some of the sets. The flowers of the pea family (*Papilionaceæ*), of the mint family (*Labiatæ*), of the morning glory, larkspur, monkshood, etc., are irregular (fig. 450). The corolla usually gives the characteristic form to the flower, and the name is usually applied to the form of the corolla.

Some of the different forms are wheel-shaped or *rotate* corolla when the petals spread out at once like the spokes of a wheel, as in the potato, tomato, or bittersweet; *salver-shaped* when the

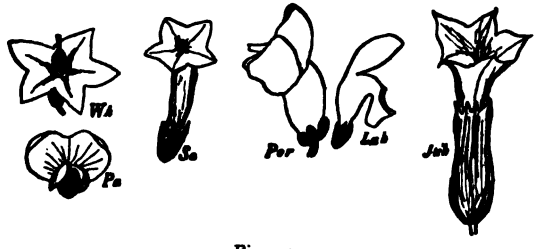


Fig. 450.

Several forms of flowers. Regular flowers. *wh*, wheel-shaped corolla; *sa*, salver-shaped; *tub*, tubular-shaped. Irregular flowers. *pa*, butterfly or papilionaceous; *per*, personate or masked flower; *lab*, gaping or ringent corolla. The two latter are called bilabiate flowers.

petals spread out at right angles from the end of a corolla tube, as in the phlox; *bell-shaped*, or *campanulate*, as in the harebell or campanula; *funnel-shaped*, as in the morning glory; *tubular*, when the ends of the petals spread but little or none from the end of the corolla tube, as in the turnip flower or in the disk florets of the composites. The *butterfly*, or *papilionaceous* corolla is peculiar as in the pea or bean. The upper petal is the "banner," the two lateral ones the "wings," and the two lower the "keel."

The *labiate* corolla is charcteristic of the mint family where the gamosepalous corolla is unequally divided, so that the two

upper lobes are sharply separated from the three lower forming two "lips." The labiate corolla of the toadflax, or snapdragon is *personate*, or *masked*, because the lower lip arches upward like a palate and closes the entrance to the corolla tube; that of the dead nettle (*Lamium*) is *ringent* or *gaping*, because the lips are spread wide apart. In some plants the labiate corolla is not very marked and differs but slightly from a regular form.

The *ligulate* or *strap-shaped* corolla is characteristic of the flowers of the dandelion or chicory, or of the ray flowers of other composites (fig. 451). The lower part of the gamosepalous corolla is tubular, and the upper part is strap-shaped, as if that part of the tube were split on one side and spread out flat.

These forms of the flower should be studied in appropriate examples in connection with flower types and relations in Chapters LVIII–LXV.

813. Union of flower parts.—In the buttercup flower all the parts of each series are separate from one another and from other series of parts. Each one is attached to the *receptacle* of the flower, which is a very much shortened portion of the flower axis. The calyx being composed of separate and distinct parts is said to be *polysepalous*, and the corolla is likewise *polypetalous*. The stamens are *distinct*, and the pistils are *simple*. In many flowers, however, there is a greater or lesser *union* of parts.

814. Union of parts of the same series or cycle.—The parts *coalesce*, either slightly or to a great extent. Usually they are not so completely coalesced but what the number of parts of the series can be determined. Where the sepals are united the calyx is *gamosepalous*, when the petals are united the corolla is *gamopetalous* (Chapter LXV).

Union of the sepals or of the corolla is quite common, but union of the stamens is rare except in a few families where it is quite characteristic. When the stamens are united by their anthers, they are *syngenæsious*. This is the case in most flowers of the composite family. When all the stamens are united into one group by their filaments, they are *monadelphous* (one brotherhood), as in holyhock, hibiscus, cotton,

marsh-mallow, etc. When they are united by their filaments in two groups, they are *diadelphous* (two brotherhoods), as in the pea and most members of the pea family. In most species of St. John's wort (Hypericum), the stamens are united in threes (*triadelphous*).

815. The carpels are often united.—The pistil is then said to be *compound*. Where the carpels are consolidated, usually the adjacent walls coalesce and thus separate the cavity of each ovary. Each cavity in the compound pistil is a *locule*. In some cases the adjacent walls disappear so that there is one common cavity for the compound pistil (examples: purslane, chickweeds, pinks, etc.). In a few cases there is a false partition (example, in the toothwort and other crucifers). The compound pistil is very often lobed slightly, so that the different carpels can be discerned. More often the styles or stigmas are distinct, and thus indicate the number of carpels united.

816. Union of the parts of different series.—While in the buttercup and many other flowers, all the different parts are inserted on the torus or receptacle, in other flowers one series of parts may be joined to another. This is *adnation* of parts, or the two or more series are *adnate*. In the morning glory the stamens are inserted on the inner face of the corolla tube; the same is true in the mint family, and there are many other examples. The insertion of parts, whether free or adnate, is usually spoken of in reference to their relation to the pistil. Thus, in the buttercup the floral envelopes and stamens are all free and *hypogenous*, they are *below* the pistil (Chapter LXII). The pistil in this case is *superior*. In the cherry, pear, etc., the petals and stamens are borne on the edge of the more or less elevated tube of the calyx, and are said to be *perigynous*, i.e., around the pistil (fig. 565). In the cranberry, huckleberry, etc., the calyx is for the most part united with the wall of the ovary with the short calyx limbs projecting from the upper surface. The petals and stamens are inserted on the edge of the calyx above the ovary; they are, therefore, *epigynous*, and the ovary being under the calyx, as it were, is *inferior* (fig. 576).

III. Arrangement of Flowers, or Mode of Inflorescence.

817. Flowers are solitary or clustered.—*Solitary flowers* are more simple in their arrangement, i.e., it is easier for us to determine and name their relation to each other and to other parts of the plant. They are either *axillary*, i.e., on short lateral shoots in the axils of ordinary foliage leaves, or they are *terminal*, i.e., they are borne on the end of the main axis of an ordinary foliage shoot. In either case they are so far separated, and the foliage leaves are so prominent, they do not form recognizable groups or clusters. The manner of arrangement of flowers on the shoot is called *inflorescence*, while the group of flowers so arranged is the *flower cluster*.

Two different modes of inflorescence are usually recognized in the arrangement of flowers on the stem. (1) The *corymbose*, or *indeterminate inflorescence* (also indefinite inflorescence), in which the flowers arise from axillary buds, and the terminal bud may continue to grow. (2) The *cymose* or *determinate inflorescence* (also *definite inflorescence*) in which the flowers arise from terminal buds. This arrests the growth of the shoot in length.

There are several advantages to the plant in the different modes of inflorescence, chief among which is the massing of the flowers, thus increasing the chances for effective pollination.

A. FLOWER CLUSTERS WITH INDETERMINATE INFLORESCENCE.

818. The simplest mode of indeterminate inflorescence is where the flowers arise in the axils of normal foliage leaves, while the terminal bud, as in the florist's smilax, the bellwort, moneywort, apricot, etc., continues to grow. The flowers are *solitary* and *axillary*. In other cases which are far more numerous, the flowers are associated into more or less definite clusters in which are a number of recognizable types. The word type used in this sense, it should be understood, does not refer to an

original structure which is the source of others. It merely refers to a mode of inflorescence which we attempt to recognize, and about which we group those forms which have a resemblance to one another. There are many forms of flower clusters which do not conform to any one of our recognized types, and are very puzzling. The evolution of the flower clusters has been *natural*, and we cannot make them all conform to an *artificial* classification. These *types* are named merely as a matter of convenience in the expression of our ideas. The types usually recognized are as follows:

819. The raceme.—The flower-shoot is more or less elongated, and the leaves are reduced to a minute size termed *bracts*, while the flowers on lateral axes are solitary in the axils of the bracts. The reduction in the size of the leaves and the somewhat limited growth of the shoot in length, makes the flowers more prominent, and brings them into closer relation than if they were formed in the axils of the leaves on the ordinary foliage shoot. The choke cherry, currant, pokeweed, sourwood, etc., are examples of a raceme (fig. 569). In most plants with the raceme type, while the inflorescence is indeterminate, and the uppermost flowers (those toward the end of the main shoot) are younger, still the period of flowering is somewhat restricted and the raceme stops growing. In a few plants, however, as in the common "shepherd's purse," the raceme continues to grow throughout the summer, so that the lower flowers may have ripened their seed while the terminal portion of the raceme is still growing and producing new flowers. Compound racemes are formed when by branching of the flower-shoot there are several racemes in a cluster, as in the false Solomon's seal (Smilacina racemosa).

820. The panicle.—The panicle is developed from the raceme type by the branching of the lateral flower-axes forming a loose open flower cluster, as in the *oat*.

821. The thyrsus is a compact panicle of pyramidal form, as in the lilac, horsechestnut, etc.

822. The corymb.—The corymb shows likewise an easy transition from the raceme type, by the shortening of the main axis

of inflorescence, and the lengthening of the lower, lateral flower peduncles so that the flower cluster is more or less flattened on top. This represents the *simple corymb*. A *compound corymb* is one in which some of the flower peduncles branch again forming secondary corymbs, as in the mountain ash. It is like a panicle with the lower flower stalks elongated.

823. The umbel.—The umbel is developed from the raceme, or corymb. The main flower-shoot remains very short or undeveloped with several flowers on long peduncles arising close together around this shortened axis, in the form of a whorl or cluster. Examples are found in the milkweed, water pennywort (Hydrocotyle), the oxheart cherry, etc. A *compound* umbel is one in which the peduncles are branched, forming secondary umbels, as in the caraway, parsnip, carrot, etc. (figs. 578, 579).

824. The spike.—In the spike the main axis is long, and the solitary flowers in the axils of the bracts are usually sessile, and often very much crowded. The plaintain, mullein (fig. 422), etc., are examples. The spike is a raceme, only the flowers are sessile and crowded. In the grasses the flower cluster is branched, and the branchlets bearing a few flowers are spikelets.

825. The head.—When the flower axis is very much shortened and the flowers crowded and sessile or nearly so, forming a globose or compressed cluster, it is a *head* or *capitulum*. The transition is from a spike by the shortening of the main axis, as in the clover, button bush (*Cephalanthus*), etc., or in the shortening of the peduncles in an umbel, as in the daisy, dandelion, and other composite flowers. In these the head is surrounded by an involucre, which in the young head often envelopes the mass of flowers, thus affording them protection. In some other composites (Lactuca, for example) the involucre affords protection for a longer period, even while the seeds are ripening.

826. The spadix.—When the main axis of the flower cluster is fleshy, the spike or head forms a *spadix*, as in the Indian turnip, the skunk cabbage, the calla, etc. The spadix is usually more or less enclosed in a *spathe*, a somewhat strap-shaped leaf.

827. The catkin.—A spike which is usually caducous, i.e.,

falls away after the maturity of the flower or fruit, is called a catkin, or an *ament*. The flower clusters of the alder, willow, (fig. 555), poplar, and the staminate flower clusters of the oak, hickory, hazel, birch, etc., are *aments*. So characteristic is this

Fig. 451.
Head of sunflower showing centripetal inflorescence of tubular flowers. (Photo by the Author.)

mode of inflorescence that the plants are called *amentiferous*, or *amentaceous*.

828. Anthesis of flowers with indeterminate inflorescence.— In the anthesis of the raceme as well as in other corymbose forms the lower (or outer) flowers being older, open first. The opening of the flowers then takes place from below, upward; or from the outside, inward toward the center of inflorescence. The *anthesis*, i.e., the opening of the flowers of corymbose forms is said to be *centripetal*, i.e., it progresses from outside, inward. The anthesis of the fuller's teazel is peculiar, since it shows both types. There are several distinct advantages to the plant where

anthesis extends over a period of time, as it favors cross pollination, favors the formation of seed in case conditions should be

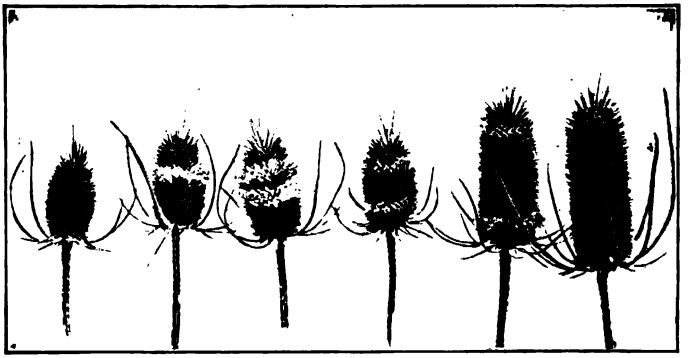


Fig. 452.
Heads of fuller's teazel in different stages of flowering.

unfavorable at one period of anthesis, distributes the drain on the plant for food, etc.

B. FLOWER CLUSTERS WITH DETERMINATE INFLORESCENCE.

829. The simplest mode of determinate inflorescence is a plant with a solitary terminal flower, as in the hepatica, the tulip, etc. The leaves in these two plants are clustered in the form of a rosette, and the aerial shoot is naked and bears the single flower at its summit. Such a flower-shoot is a *scape*. As in the case of the indeterminate inflorescence, so here the larger number of flower-shoots are more complex and specialized, resulting in the evolution of flower clusters or masses. Accompanying the association of flowers into clusters there has been a reduction in leaf surface on the flower-shoot so that the flowers predominate in mass and are more conspicuous. Among the recognized modes of determinate inflorescence, the following are the chief ones:

830. The cyme.—In the cyme the terminal flower on the main axis opens first and the remaining flowers are borne on lateral shoots, which arise from the axils of leaves or bracts, below

These lateral shoots usually branch and elongate so that the terminal flowers on all the branches reach nearly the same height as the terminal flower on the main shoot, forming a somewhat flattened or convex top of the flower cluster. This is illustrated

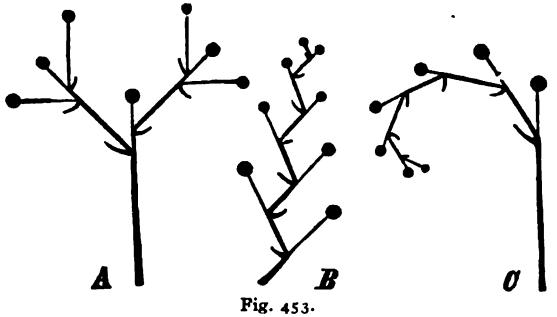


Fig. 453.

Diagrams of cymose inflorescence. *A*, dichasium; *B*, scorpioid cyme; *C*, helicoid cyme. (After Strasburger.)

in the basswood flower. The anthesis of the cyme is *centrifugal*, i.e., from the inside outward to the margin. But it is often more or less mixed, since the lateral shoots if they bear more than one flower are dimunitive cymes and the terminal flower opens before the lateral ones. Where the flower cluster is quite large and the branching quite extensive, *compound cymes* are formed, as in the dogwood, hydrangea, etc.

831. The helicoid cyme.—Where successive lateral branching takes place, and always continues on the same side a curved flower cluster is formed, as in the forget-me-not and most members of the borage family. This is known as a *helicoid cyme* (fig. 453, *C*). Each new branch becomes in turn the "false" axis bearing a new branch on the same side.

832. The scorpioid cyme.—*A scorpioid cyme* (fig. 453, *B*) is formed where each new branch arises on alternate sides of the "false" axis.

833. The forking cyme is where each "false" axis produces two branches opposite, so that it represents a false dichotomy (example, the flower cluster of chickweed).

834. Some of these flower clusters are peculiar and it is diffi-

cult to see how the helicoid, or scorpioid, cymes are of any advantage to the plant over a true cyme. The inflorescence of the plant being determinate, if the flowering is to be extended over a considerable period a peculiar form would necessarily result. In the *helicoid cyme* continued branching takes place on one side, and the result in the forget-me-not is a continued inflorescence in its effect like that of a continued raceme (compare shepherd's-purse). But we should not expect that all of the complex and specialized structures from simple and generalized ones are beneficial to the plant. In many plants we recognize evolution in the direction of advantageous structures. But since the plant cannot consciously evolve these structures, we must also recognize that there may be phases of retrogression in which the structures evolved are not so beneficial to the plant as the more simple and generalized ones of its ancestors. Variation and change do not result in advancing the plant or plant structures merely along the lines which will be beneficial. The tendency is in all directions. The result in general may be diagramed by a tree with divergent and wide-reaching branches. Some die out; others remain subordinate or dormant; while still others droop downward, showing a retrogression. But in this backward evolution they do not return to the condition of their ancestors, nor is the same course retraced. A new downward course is followed just as the downward-growing branch follows a course of its own, and does not return in the trunk.

CHAPTER XLIII.

POLLINATION.

Origin of heterospory, and the necessity for pollination.

835. Both kinds of sexual organs on the same prothallium.—In the ferns, as we have seen, the sexual organs are borne on the prothallium, a small, leaf-like, heart-shaped body growing in moist situations. In a great many cases both kinds of sexual organs are borne on the same prothallium. While it is perhaps not uncommon, in some species, that the egg cell in an archegonium may be fertilized by a spermatozoid from an antheridium on the same prothallium, it happens many times that it is fertilized by a spermatozoid from another prothallium. This may be accomplished in several ways. In the first place antheridia are usually found much earlier on the prothallium than are the archegonia. When these antheridia are ripe, the spermatozoids escape before the archegonia on the same prothallium are mature.

836. Cross fertilization in monœcious prothallia.—By swimming about in the water or drops of moisture which are at times present in these moist situations, these spermatozoids may reach and fertilize an egg which is ripe in an archegonium borne on another and older prothallium. In this way what is termed cross fertilization is brought about nearly as effectually as if the prothallia were diœcious, i.e. if the antheridia and archegonia were all borne on separate prothallia.

837. Tendency toward diœcious prothallia.—In other cases some fern prothallia bear chiefly archegonia, while others bear only antheridia. In these cases cross fertilization is enforced because of this separation of the sexual organs on different prothallia. These different prothallia, the male and female, are largely due to a difference in food supply, as has been clearly proven by experiment.

838. The two kinds of sexual organs on different prothallia.—In the horsetails (equisetum) the separation of the sexual organs on different prothallia has become quite constant. Although all the spores are alike, so far as we can determine, some produce small male plants exclusively, while others produce

large female plants, though in some cases the latter bear also antheridia. It has been found that when the spores are given but little nutriment they form male prothallia, and the spores supplied with abundant nutriment form female prothallia.

839. Permanent separation of sexes by different amounts of nutriment supplied the spores.—This separation of the sexual organs of different prothallia, which in most of the ferns, and in equisetum, is dependent on the chance supply of nutriment to the germinating spores, is made certain when we come to such plants as isoetes and selaginella. Here certain of the spores receive more nutriment while they are forming than others. In the large sporangia (macrosporangia) only a few of the cells of the spore-producing tissue form spores, the remaining cells being dissolved to nourish the growing macrospores, which are few in number. In the small sporangia (microsporangia) all the cells of the spore-producing tissue form spores. Consequently each one has a less amount of nutriment, and it is very much smaller, a microspore. The sexual nature of the prothallium in selaginella and isoetes, then, is predetermined in the spores while they are forming on the sporophyte. The microspores are to produce male prothallia, while the macrospores are to produce female prothallia.

840. Heterospory.—This production of two kinds of spores by isoetes, selaginella, and some of the other fern plants is *heterospory*, or such plants are said to be *heterosporous*. Heterospory, then, so far as we know from living forms, has originated in the fern group. In all the higher plants, in the gymnosperms and angiosperms, it has been perpetuated, the microspores being represented by the pollen, while the macrospores are represented by the embryo sac; the male organ of the gymnosperms and angiosperms being the antherid cell in the pollen or pollen tube, or in some cases perhaps the pollen grain itself, and the female organ in the angiosperms perhaps reduced to the egg cell of the embryo sac.

841. In the pteridophytes water serves as the medium for conveying the sperm cell to the female organ.—In the ferns and their allies, as well as in the liverworts and mosses, surface water is a necessary medium through which the generative or sperm cell of the male organ, the spermatozoid, may reach the germ cell of the female organ. The sperm cell is here motile. This is true in a large number of cases in the algæ, which are mostly aquatic plants, while in other cases currents of water float the sperm cell to the female organ.

842. In the higher plants a modification of the prothallium is necessary.—As we pass to the gymnosperms and angiosperms, however, where the primitive phase (the gametophyte) of the plants has become dependent solely on the modern phase (the sporophyte) of the plant, surface water no longer serves as the medium through which a motile sperm cell reaches the egg cell to fertilize it. The female prothallium, or macrospore, is, in nearly all

cases, permanently enclosed within the sporangium, so that if there were motile sperm cells on the outside of the ovary, they could never reach the egg to fertilize it.

843. But a modification of the microspore, the pollen tube, enables the sperm cell to reach the egg cell. The tube grows through the nucellus, or first through the tissues of the ovary, deriving nutriment therefrom.

844. But here an important consideration should not escape us. The pollen grains (microspores) must in nearly all cases first reach the pistil, in order that in the growth of this tube a channel may be formed through which the generative cell can make its way to the egg cell. The pollen passes from the anther locule, then, to the stigma of the ovary. This process is termed *pollination.*

Pollination.

845. Self pollination, or close pollination.—Perhaps very few of the admirers of the pretty blue violet have ever noticed that there are other flowers than those which appeal to us through the beautiful colors of the petals. How many have observed that the brightly colored flowers of the blue violet rarely "set fruit"? Underneath the soil or débris at the foot of the plant are smaller flowers on shorter, curved stalks, which do not open. When the anthers dehisce, they are lying close upon the stigma of the ovary, and the pollen is deposited directly upon the stigma of the same flower. This method of pollination is *self pollination*, or *close pollination.* These small, closed flowers of the violet have been termed "*cleistogamous*," because they are pollinated while the flower is closed, and fertilization takes place as a result.

But self pollination takes place in the case of some open flowers. In some cases it takes place by chance, and in other cases by such movements of the stamens, or of the flower at the time of the dehiscence of the pollen, that it is quite certainly deposited upon the stigma of the same flower.

846. Wind pollination.—The pine is an example of wind-pollinated flowers. Since the pollen floats in the air or is carried by the "wind," such flowers are *anemophilous.* Other anemophilous flowers are found in other conifers, in grasses, sedges, many of the ament-bearing trees, and other dicotyledons. Such plants produce an abundance of pollen and always in the form of "dust," so that the particles readily separate and are borne on the wind.

847. Pollination by insects.—A large number of the plants which we have noted as being anemophilous are monœcious or dicœcious, i.e. the stamens and pistils are borne in separate flowers. The two kinds of flowers thus formed, the male and the female, are borne either on the same individual (monœcious) or on different individuals (dicœcious). In such cases cross pollination,

i.e. the pollination of the pistil of one flower by pollen from another, is sure to take place, if it is pollinated at all. Even in monœcious plants cross pollination often takes place between flowers of different individuals, so that

Fig. 454.

Viola cucullata; blue flowers above, cleistogamous flowers smaller and curved below. Section of pistil at right.

more widely different stocks are united in the fertilized egg, and the strain is kept more vigorous than if very close or identical strains were united.

848. But there are many flowers in which both stamens and pistils are present, and yet in which cross pollination is accomplished through the agency of insects.

859. Pollination of the bluet.—In the pretty bluet the stamens and styles of the flowers are of different length as shown in figures 455, 456. The stamens of the long-styled flower are at about the same level as the stigma of the short-styled flower, while the stamens of the latter are on

about the same level as the stigma of the former. What does this interesting relation of the stamens and pistils in the two different flowers mean? As the butterfly thrusts its "tongue" down into the tube of the long-styled flower

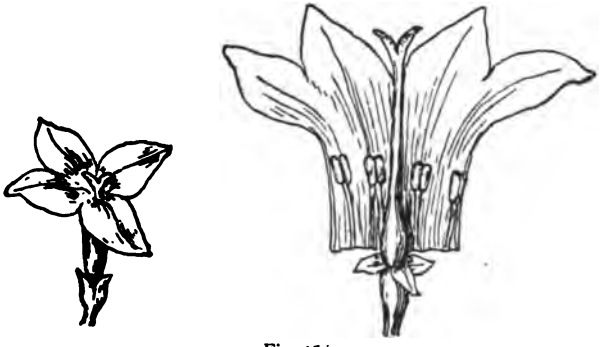


Fig. 45 *b*.
Dichogamous flower of the bluet (Houstonia cœrulea), the long-styled form.

for the nectar, some of the pollen will be rubbed off and adhere to it. When now the butterfly visits a short-styled flower this pollen will be in the right position to be rubbed off onto the stigma of the short style. The positions of

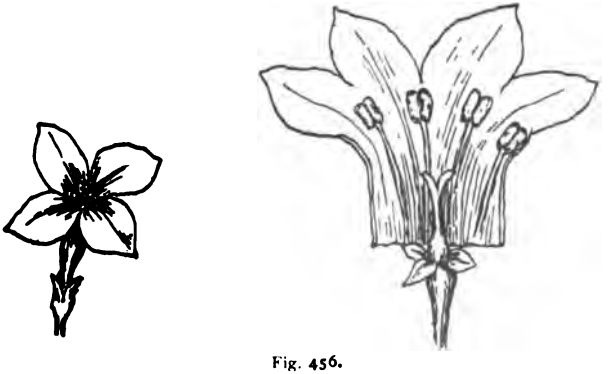


Fig. 45*c*.
Dichogamous flower of bluet (Houstonia cœrulea), the short-styled form.

the long stamens and long style are such that a similar cross pollination will be effected.

350. Pollination of the primrose.—In the primroses, of which we have examples growing in conservatories, that blossom during the winter, we have almost identical examples of the beautiful adaptations for cross pollination by insects found in the bluet. The general shape of the corolla is

the same, but the parts of the flower are in fives, instead of in fours as in the bluet. While the pollen of the short-styled primulas sometimes must fall on the stigma of the same flower, Darwin has found that such pollen is

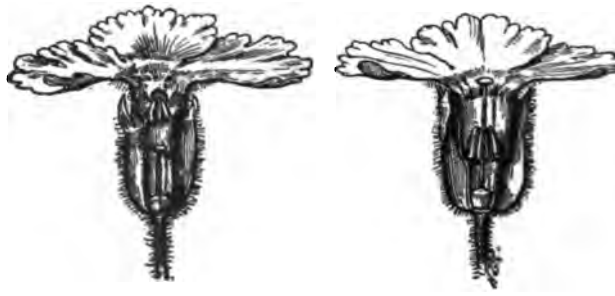


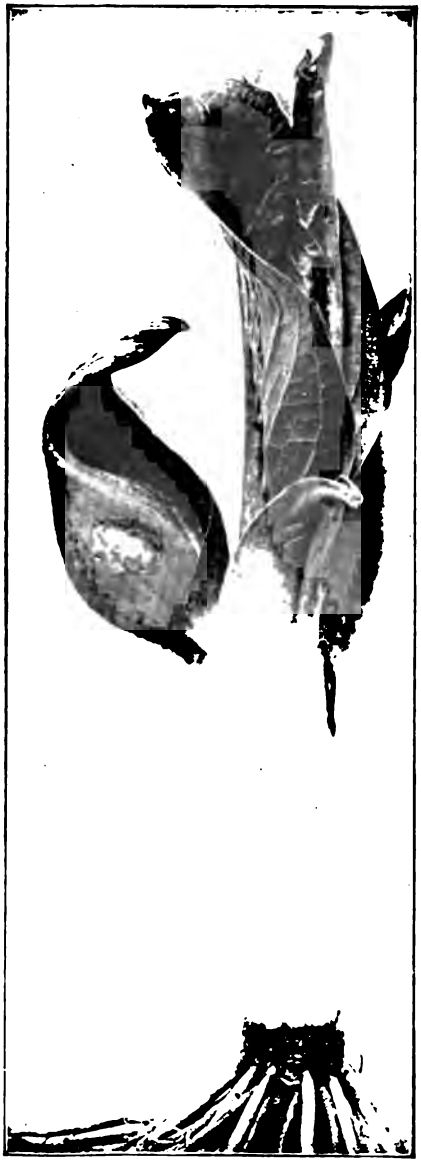
Fig. 457.
Dichogamous flowers of primula.

not so potent on the stigma of its own flower as on that of another, an additional provision which tends to necessitate cross pollination.

In the case of some varieties of pear trees, as the bartlett, it has been found that the flowers remain largely sterile not only to their own pollen, or pollen of the flowers on the same tree, but to all flowers of that variety. However, they become fertile if cross pollinated from a different variety of pear.

851. Pollination of the skunk's cabbage.—In many other flowers cross pollination is brought about through the agency of insects, where there is a difference in time of the maturing of the stamens and pistils of the same flower. The skunk's cabbage (Spathyema fœtida), though repulsive on account of its fetid odor, is nevertheless a very interesting plant to study for several reasons. Early in the spring, before the leaves appear, and in many cases as soon as the frost is out of the hard ground, the hooked beak of the large fleshy spathe of this plant pushes its way through the soil.

If we cut away one side of the spathe as shown in fig. 459 we shall have the flowering spadix brought closely to view. In this spadix the pistil of each crowded flower has pushed its style through between the plates of armor formed by the converging ends of the sepals, and stands out alone with the brush-like stigma ready for pollination, while the stamens of all the flowers of this spadix are yet hidden beneath. The insects which pass from the spadix of one plant to another will, in crawling over the projecting stigmas, rub off some of the pollen which has been caught while visiting a plant where the stamens are scattering their pollen. In this way cross pollination is brought about. Such flowers, in which the stigma is prepared



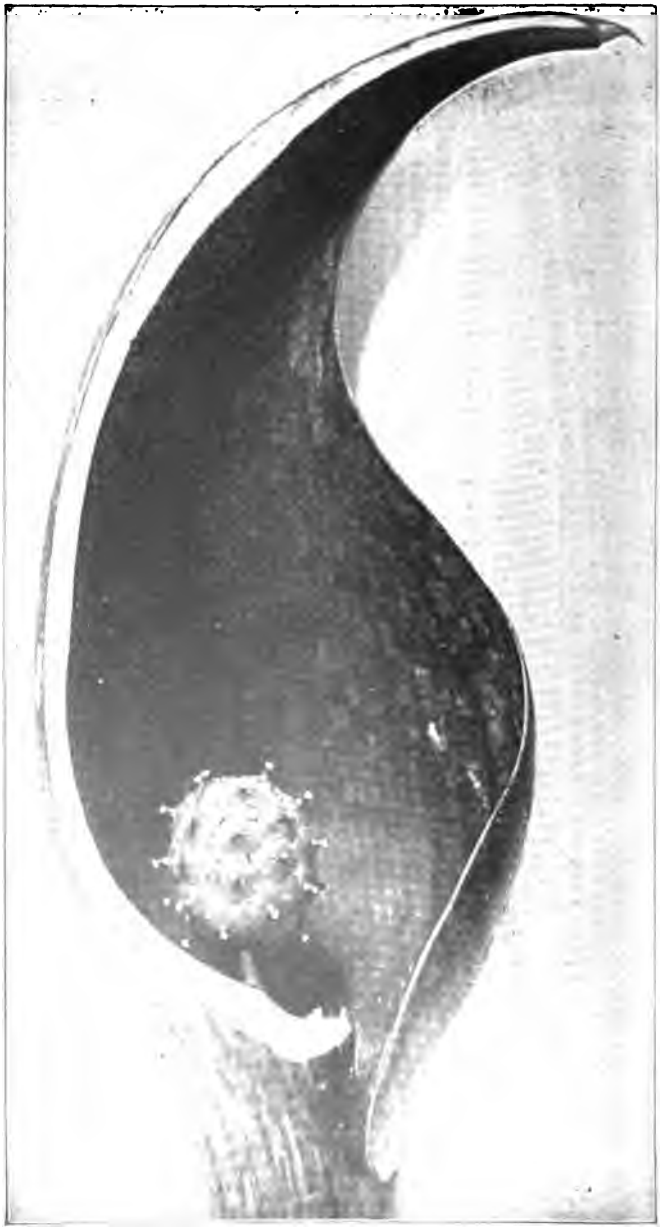


Fig. 459.

Fig. 460.
Skunk's cabbage; upper flowers proterandrous, lower ones proterogynous.

for pollination before the anthers of the same flower are ripe, are *proterogynous*.

852. Now if we observe the spadix of another plant we may see a condition of things similar to that shown in fig. 460. In the flowers in the upper part of the spadix here the anthers are wedging their way through between the armor-like plates formed by the sepals, while the styles of the same flowers are still beneath, and the stigmas are not ready for pollination. Such flowers are *proterandrous*, that is, the anthers are ripe before the stigmas of the same flowers are ready for pollination. In this spadix the upper flowers are proterandrous, while the lower ones are proterogynous, so that it might happen here that the lower flowers would be pollinated by the pollen falling on them from the stamens of the upper flowers. This would be cross pollination so far as the flowers are concerned, but not so far as the plants are concerned. In some individuals, however, we find all the flowers proterandrous.

853 Spiders have discovered this curious relation of the flowers and insects.—On several different occasions, while studying the adaptations of the flowers of the skunk's cabbage for cross pollination, I was interested to find that the spiders long ago had discovered something of the kind, for they spread their nets here to catch the unwary but useful insects. I have not seen the net spread over the opening in the spathe, but it is spread over the spadix within, reaching from tip to tip of either the stigmas, or stamens, or both. Behind the spadix crouches the spider-trapper. The insect crawls over the edge of the spadix, and plunges unsuspectingly into the dimly lighted chamber below, where it becomes entangled in the meshes of the net.

Flowers in which the ripening of the anthers and maturing of the stigmas occur at different times are also said to be *dichogamous*.

854 Pollination of jack-in-the-pulpit.—The jack-in-the-pulpit (Arisæma triphyllum has made greater advance in the art of enforcing cross pollination. The larger number of plants here are, as we have found, dicœcious, the staminate flowers being on the spadix of one plant, while the pistillate flowers are on the spadix of another. In a few plants, however, we find both female and male flowers on the same spadix.

855 The pretty bellflower (Campanula rotundifolia) is dichogamous and proterandrous (fig. 462). Many of the composites are also dichogamous.

856. Pollination of orchids.—But some of the most marvellous adaptations for cross pollination by insects are found in the orchids, or members of the orchis family. The larger number of the members of this family grow in the tropics. Many of these in the forests are supported in lofty trees where they are brought near the sunlight, and such are called "epiphytes." A number of species of orchids are distributed in temperate regions.

857. Cypripedium, or lady-slipper.—One species of the lady-slipper is hown in fig. 468. The labellum in this genus is shaped like a shoe, as one

Fig. 461.
A group of jacks.

n see by the section of the flower in fig. 468. The stigma is situated at *st*, hile the anther is situated at *a*, upon the style. The insect enters about e middle of the boat-shaped labellum. In going out it passes up and out

at the end near the flower stalk. In doing this it passes the stigma first and the anther last, rubbing against both. The pollen caught on the head of

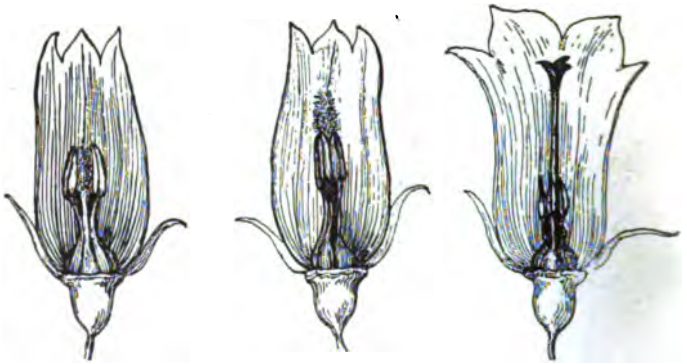


Fig. 462.

Proterandry in the bell-flower (campanula). Left figure shows the syngenœcious stamens surrounding the immature style and stigma. Middle figure shows the immature stigma being pushed through the tube and brushing out the pollen; while in the right-hand figure, after the pollen has disappeared, the lobes of the stigma open out to receive pollen from another flower.

the insect, will not touch the stigma of the same flower, but will be in position to come in contact with the stigma of the next flower visited

858. Epipactis.—In epipactis the action of the pollinia, which move downward, is described in fig. 469.

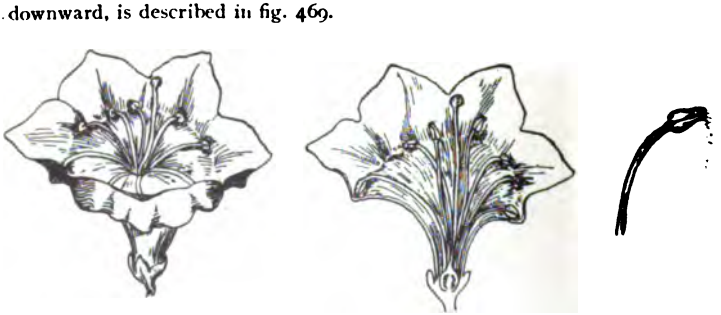


Fig. 463.

Kalmia latifolia, showing position of anthers before insect visits, and at the right the scattering of the pollen when disturbed by insects. Middle figure section of flower.

849. In some of the tropical orchids the pollinia are set free when the insect touches a certain part of the flower, and are thrown in such a way that the disk of the pollinium strikes the insect's head and stands upright. By the time the insect reaches another flower the pollinium has bent downward suffi-

ciently to strike against the stigma when the insect alights on the labellum. In the mountains of North Carolina I have seen a beautiful little orchid, in which, if one touches a certain part of the flower with a lead-pencil or other suitable object, the pollinium is set free suddenly, turns a complete somersault in the air, and lands with the disk sticking to the pencil. Many of the

Fig. 464.
Spray of leaves and flowers of cytisus.

orchids grown in conservatories can be used to demonstrate some of these peculiar mechanisms.

860. Pollination of the canna.—In the study of some of the marvellous adaptations of flowers for cross pollination one is led to inquire if, after all, plants are not intelligent beings, instead of mere automatons which respond

Fig. 465.
Flower of cytisus grown in conservatory. Same flower scattering pollen.

to various sorts of stimuli. No plant has puzzled me so much in this respect as the canna, and any one will be well repaid for a study of recently opened flowers, even though it may be necessary to rise early in the morning to unravel the mystery, before bees or the wind have irritated the labellum. The canna flower is a bewildering maze of petals and petal-like members.

The calyx is green, adherent to the ovary, and the limb divides into three, lanceolate lobes. The petals are obovate and spreading, while the stamens have all changed to petal-like members, called *staminodia*. Only one still shows its stamen origin, since the anther is seen at one side, while the filament is expanded laterally and upwards to form the *staminodium*.

Fig. 466.

Spartium, showing the dusting of the pollen through the opening keels on the under side of an insect. (From Kerner and Oliver.)

861. The ovary has three locules, and the three styles are usually united into a long, thin, strap-shaped style, as seen in the figure, though in some cases three, nearly distinct, filamentous styles are present. The end of this strap-shaped style has a peculiar curve on one side, the outline being some-

times like a long narrow letter S. It is on the end of this style, and along the crest of this curve, that the stigmatic surface lies, so that the pollen

Fig. 467.
Cypripedium.

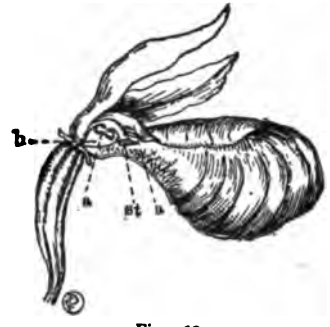


Fig. 468.

Section of flower of cypripedium. *st*, stigma; *a*, at the left stamen. The insect enters the labellum at the center, passes under and against the stigma, and out through the opening *b*, where it rubs against the pollen. In passing through another flower this pollen is rubbed off on the stigma.

must be deposited on the stigmatic end or margin in order that fertilization may take place.

862. If we open carefully canna-flower buds which are nearly ready to open naturally, by unwrapping the folded petals and staminodia, we shall see the anther-bearing

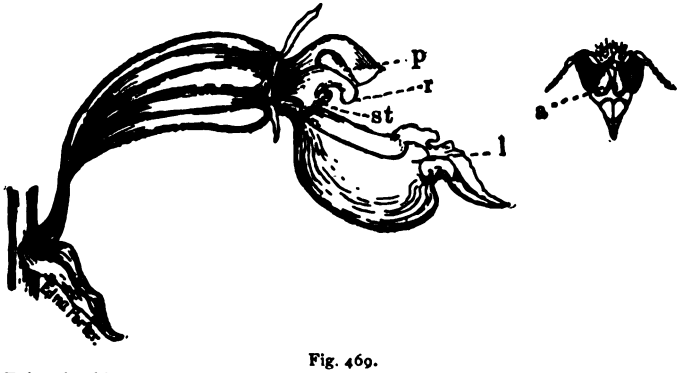


Fig. 469.

Epipactis with portion of perianth removed to show details. *l*, labellum; *st*, stigma; *r*, rostellum; *p*, pollinium. When the insect approaches the flower its head strikes the disk of the pollinium and pulls the pollinium out. At this time the pollinium stands up out of the way of the stigma. By the time the insect moves to another flower the pollinia have moved downward so that they are in position to strike the stigma and leave the pollen. At the right is the head of a bee, with two pollinia (*a*) attached.

staminodium is so wrapped around the flattened style that the anther lies closely pressed against the face of the style, near the margin *opposite that on which the stigma lies.*

863. The walls of the anther locules which lie against the style become changed to a sticky substance for their entire length, so that they cling firmly to the surface of the style and also to the mass of pollen within the locules. The result is that when the flower opens, and this staminodium unwraps itself from the embrace of the style, the mass of pollen is left there deposited, while the empty anther is turned around to one side.

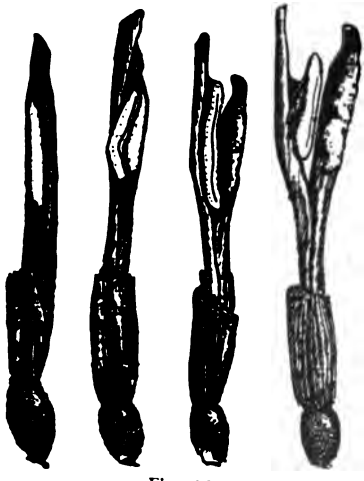


Fig. 470.

Canna flowers with the perianth removed to show the depositing of the pollen on the style by the stamen.

868. Why does the flower deposit its own pollen on the style? Some have regarded this as the act of pollination, and have concluded, therefore, that cannas are necessarily self pollinated, and that cross pollination does not take place. But why is there such evident care to deposit the pollen on the side of the style away from the stigmatic margin? If we visit the cannas some morning, when a number of the flowers have just opened, and the bumblebees are humming around seeking for nectar, we may be able to unlock the secret.

864. We see that in a recently opened canna flower, the petal which directly faces the style in front stands upward quite close to it, so that the flower now is somewhat funnelshaped. This front petal is the *labellum*, and is the landing place for the bumblebee as he alights on the flower. Here he comes humming along and alights on the labellum with his head so close to the style that it touches it. But just the instant that the bee attempts to crowd down in the flower the labellum suddenly bends downward, as shown in fig. 468. In so doing the head of the bumblebee scrapes against the pollen, bearing some of it off. Now while the bee is sipping the nectar it is too far below the stigma to deposit any pollen on the latter. When the bumblebee flies to another newly opened flower, as it alights, some of the pollen of the former flower is brushed on the stigma.

865. One can easily demonstrate the sensitiveness of the labellum of recently opened canna flowers, if the labellum has not already moved down in response to some stimulus. Take a lead-pencil, or a knife blade, or even

the finger, and touch the upper surface of the labellum by thrusting it between the latter and the style. The labellum curves quickly downward.

866. Sometimes the bumblebees, after sipping the nectar, will crawl up over the style in a blundering manner. In this way the flower may be pol-

Fig. 471.

Pollination of the canna flower by bumblebee. Canna flower. Pollen on style, stamen at left.

linated with its own pollen, which is equivalent to self pollination. Undoubtedly self pollination does take place often in flowers which are adapted, to a greater or less degree, for cross pollination by insects.

CHAPTER XLIV.

THE FRUIT.

I. Parts of the Fruit.

867. After the flower comes the fruit.—With the perfection of the fruit the seed is usually formed. This is the end towards which the energies of the plant have been directed. While the seed consists only of the ripened ovule and the contained embryo, the fruit consists of the ripened ovary in addition, and in many cases with other accessory parts, as calyx, receptacle, etc., combined with it. The wall of the ripened ovary is called a *pericarp*, and the walls of the ovary form the walls of the fruit.

868. Pericarp, endocarp, exocarp, etc.—This is the part of the fruit which envelops the seed and may consist of the carpels alone, or of the carpels and the adherent part of the receptacle, or calyx. In many fruits the pericarp shows a differentiation into layers, or zones of tissue, as in the cherry, peach, plum, etc. The outer, which is here soft and fleshy, is *exocarp*, while the inner, which is hard, is the *endocarp*. An intermediate layer is sometimes recognized and is called *mesocarp*. In such cases the skin of the fruit is recognized as the *epicarp*. Epicarp and mesocarp are more often taken together as exocarp.

In general fruits are *dry* or *fleshy*. Dry fruits may be grouped under two heads. Those which open at maturity and scatter the seed are *dehiscent*. Those which do not open are *indehiscent*.

II. Indehiscent Fruits.

869. The akene.—The thin dry wall of the ovary encloses the single seed. It usually does not open and free the seed within. Such a fruit is an *akene*. An *akene* is a dry, *indehiscent* fruit. All of the crowded but separate pistils in the buttercup flower when ripe make a head of akenes, which form the fruit of the buttercup. Other examples of akenes are found in other members of the buttercup family, also in the composites, etc. The sunflower seed is a good example of an akene.

Fig. 472. Seed, or akene, of buttercup.

870. The samara.—The winged fruits of the maple (fig. 574), elm, etc., are indehiscent fruits. They are sometimes called key fruits.

Fig. 473. Fruit of red oak. An acorn.

871. The caryopsis is a dry fruit in which the seed is consolidated with the wall of the ovary, as in the wheat, corn, and other grasses.

872. The schizocarp is a dry fruit consisting of several locules (from a *syncarpous gynœcium*). At maturity the carpels separate from each other, but do not themselves dehisce and free the seed, as in the carrot family, mallow family.

873. The acorn.—The acorn fruit consists of the acorn and the "cup" at the base in which the acorn sits. The cup is a curious structure, and is supposed to be composed of an involucre of numerous small leaves at the base of the pistillate flower, which become consolidated into a hard cup-shaped body. When the acorn is ripe it easily separates from the cup, but the hard pericarp forming the "shell" of the acorn remains closed. Frost may cause it to crack, but very often the pericarp is split open at the smaller end by wedge-like pressure exerted by the emerging radicle during germination.

874. The hazelnut, chestnut, and beechnut.—In these fruits a crown of leaves (involucre) at the base of the flower grows around

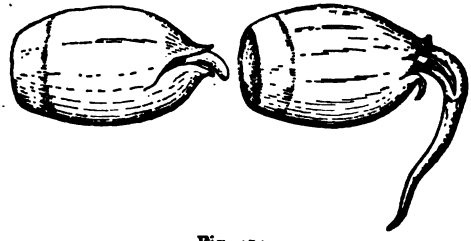


Fig. 474.
Germinating acorn of white oak.

the nut and completely envelops it, forming the husk or burr. When the fruit is ripe the nut is easily shelled out from the husk. In the beechnut and chestnut the burr dehisces as it dries and allows the nut to drop out. But the fruit is not dehiscent, since the pericarp is still intact and encloses the seed.

875. The hickory-nut, walnut, and butternut.—In these fruits the "shuck" of the hickory-nut and the "hull" of the walnut and butternut are different from the involucre of the acorn or hazelnut, etc. In the hickory-nut the "shuck" probably consists partly of calyx and partly of involucral bracts consolidated, probably the calyx part predominating. This part of the fruit splits open as it dries and frees the "nut," the pericarp being very hard and indehiscent. In the walnut and butternut the "hull" is probably of like origin as the "shuck" of the hickory nut, but it does not split open as it ripens. It remains fleshy. The walnut and butternut are often called *drupes* or *stone fruits*, but the fleshy part of the fruit is not of the same origin as the fleshy part of the true drupes, like the cherry, peach, plum, etc.

III. Dehiscent Fruits.

876. Of the dehiscent fruits several prominent types are recognized, and in general they are sometimes called *pods*. There is a single carpel (simple pistil), and the pericarp is dry (gynœ-

cium *apocarpous*); or where there are several carpels united the pistil is compound (gynœcium *syncarpous*).

877. The capsule.—When the capsule is *syncarpous* it may dehisce in three different ways: 1st. When the carpels split along the line of their union with each other longitudinally (*septicidal dehiscence*), as in the azalea or rhododendron. 2d. When the carpels *split down the middle line* (*loculicidal dehiscence*), as in the fruit of the iris, lily, etc. 3d. When the carpels open by pores (*poricidal dehiscence*), as in the poppy. Some syncarpous capsules have but one locule, the partitions between the different locules when young having disappeared. The "bouncing-bet" is an example, and the seeds are attached to a central column in four rows corresponding to the four locules present in the young stage.

Fig. 475.
Diagrams illustrating three types (in cross-section) of the dehiscence of dry fruits. *Loc*, loculicidal; *Sep*, Septicidal, Septifragal.

878. A follicle is a capsule with a single carpel which splits open along the ventral or upper suture, as in the larkspur, peony.

879. The legume, or true pod, is a capsule with a single carpel which splits along both sutures, as the pea, bean, etc. As the pod ripens and dries, a strong twisting tension is often produced, which splits the pod suddenly, scattering the seeds.

Fig. 476.
Fruit of sweet pea; a pod.

880. The silique.—In the toothwort, shepherd's-purse, and nearly all of the plants in the mustard family the fruit consists of two united carpels, which separate at maturity, leaving the partition wall persistent. Such a fruit is a *silique;* when short it is a *silicle*, or *pouch.*

881. A pyxidium, or pyxis, is a capsule which opens with a lid, as in the plantain.

IV. Fleshy and Juicy Fruits.

882. The drupe, or stone-fruit.—In the plum, cherry, peach, apricot, etc., the outer portion (exocarp) of the pericarp (ovary) becomes fleshy, while the inner portion (endocarp) becomes hard and stony, and encloses the seed, or "pit." Such a fruit is known as a drupe, or as a stone-fruit. In the almond the fleshy part of the fruit is removed.

883. The raspberry and blackberry.—While these fruits are

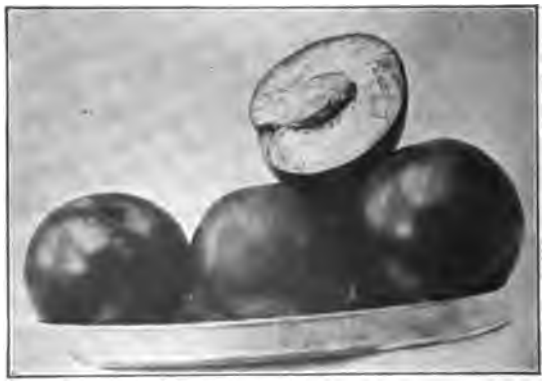


Fig. 477.
Drupe, or stone-fruit, of plum.

known popularly as "berries," they are not berries in the technical sense. Each ovary, or pericarp, in the flower forms a single small fruit, the outer portion being fleshy and the inner stony, just as in the cherry or plum. It is a *drupelet* (little drupe). All of the drupelets together make the "berry," and as they ripen the separate drupelets cohere more or less. It is a collection, or aggregation, of fruits, and consequently they are sometimes called *collective fruits*, or *aggregate fruits*. In the raspberry the fruit separates from the receptacle, leaving the latter on the stem, while the drupelets of the blackberry and dewberry adhere to the receptacle and the latter separates from the stem.

884. The berry.—In the true berry both exocarp (including mesocarp) and endocarp are fleshy or juicy. Good examples are found in cranberries, huckleberries, gooseberries, currants, snowberries, tomatoes, etc. The calyx and wall of the pistil are adnate, and in fruit become fleshy so that the seeds are imbedded in the pulpy juice. The seeds themselves are more or less stony. In the case of berries, as well as in strawberries, raspberries, and blackberries, the fruits are eagerly sought by birds and other animals for food. The seeds being hard are not digested, but are passed with the other animal excrement and thus gain dispersal.

V. Reinforced, or Accessory, Fruits.

When the torus (receptacle) is grown to the pericarp in fruit, the fruit is said to be *reinforced.* The torus may enclose the pericarps, or the latter may be seated upon the torus.

885. In the strawberry the receptacle of the flower becomes

Fig. 478.
Fruit of raspberry.

larger and fleshy, while the "seeds," which are akenes, are sunk in the surface and are hard and stony. The strawberry thus

differs from the raspberry and blackberry, but like them it is not a true berry.

886. The apple, pear, quince, etc.—In the flower the calyx, corolla, and stamens are perigynous, i.e., they are seated on the margin of the receptacle, or torus, which is elevated around the pistils. In fruit the receptacle becomes consolidated with the wall of the ovary (with the pericarp). The torus thus *reinforces* the pericarp. The torus and outer portion of the pericarp become fleshy, while the inner portion of the pericarp becomes papery and forms the "core." The calyx persists on the free end of the fruit. Such a fruit is called a *pome*. The receptacle, or torus, of the rose-flower, closely related to the apple, is instructive when used in comparison. The rose-fruit is called a "hip."

887. The pepo.—The fruit of the squash, pumpkin, cucumber, etc., is called a *pepo*. The outer part of the fruit is the receptacle (or torus), which is consolidated with the outer part of the three-loculed ovary. The calyx, which, with the corolla and stamens, was epigynous, falls off from the young fruit.

VI. Fruits of Gymnosperms.

The fruits of the gymnosperms differ from nearly all of the angiosperms in that the seed formed from the ripened ovule is naked from the first, i.e., the ovary, or carpel, does not enclose the seed.

888. The cone-fruit is the most prominent fruit of the gymnosperms, as can be seen in the cones of various species of pine, spruce, balsam, etc.

889. Fleshy fruits of the gymnosperms.—Some of the fleshy fruits resemble the stone-fruits and berries of the angiosperms. The *cedar "berries,"* for example, are fleshy and contain several seeds. But the fleshy part of the fruit is formed, not from pericarp, since there is no pericarp, but from the outer portion of the ovules, while the inner walls of the ovules form the hard stone surrounding the endosperm and embryo. An examination

of the pistillate flower of the cedar (juniper) shows usually three flask-shaped ovules on the end of a fertile shoot subtended by as many bracts (carpels?). The young ovules are free, but as they grow they coalesce, and the outer walls become fleshy, forming a berry-like fruit with a three-rayed crevice at the apex marking the number of ovules. The red fleshy fruit of the yew (taxus) resembles a drupe which is open at the apex. The stony seed is formed from the single ovule on the fertile shoot, while the red cup-shaped fleshy part is formed from the outer integument of the ovule. The so-called "aril" of the young ovule is a rudimentary outer integument.

The fruit of the maidenhair tree (ginkgo) is about the size of a plum and resembles very closely a stone-fruit. But it is merely a ripened ovule, the outer layer becoming fleshy while the inner layer becomes stony and forms the pit which encloses the embryo and endosperm. The so-called "aril," or "collar," at the base of the fruit is the rudimentary carpel, which sometimes is more or less completely expanded into a true leaf. The fruit of cycas is similar to that of ginkgo, but there is no collar at the base. In zamia the fruit is more like a cone, the seeds being formed, however, on the under sides of the scales.

VII. The "Fruit" of Ferns, Mosses, etc.

890. The term "fruit" is often applied in a general or popular sense to the groups of spore-producing bodies of ferns (*fruit-dots*, or *sori*), the spore-capsules of mosses and liverworts, and also to the fruit-bodies, or spore-bearing parts, of the fungi and algæ.

CHAPTER XLV.

SEED DISPERSAL.

891. Means for dissemination of seeds.—During late summer or autumn a walk in the woods or afield often convinces us of the perfection and variety of means with which plants are provided for the dissemination of their seeds, especially when we discover that several hundred seeds or fruits of different plants are stealing a ride at our expense and annoyance. The hooks and barbs on various seed-pods catch into the hairs of passing animals and the seeds may thus be transported considerable distances. Among the plants familiar to us, which have such contrivances for unlawfully gaining transportation, are the beggar-ticks or stick tights, or sometimes called bur-marigold (bidens), the tick-treefoil (desmodium), or cockle-bur (xanthium), and burdock (arctium).

Fig. 479.
Bur of bidens or bur-marigold, showing barbed seeds.

Fig. 480.
Seed pod of tick-treefoil (desmodium); at the right some of the hooks greatly magnified.

892. Other plants like some of the sedges, etc., living on the margins of streams and of lakes, have seeds which are provided with floats. The wind or the flowing of the water transports them often to distant points.

893. Many plants pos ess attractive devices, and offer a substantial reward, as a price for the distribution of their seeds. Fruits and berries are devoured by birds and other animals ; the seeds within, often passing unharmed, may be carried long distances. Starchy and albuminous seeds and

Fig. 481.

Seeds of geum showing the hooklets where the end of the style is kneed.

grains are also devoured, and while many such seeds are destroyed, others are not injured, and finally are lodged in suitable places for growth, often remote from the original locality. Thus animals willingly or unwillingly become agents in the dissemination of plants over the earth. Man in the development of commerce is often responsible for the wide distribution of harmful as well as beneficial species.

894. Other plants are more independent, and mechanisms are employed for violently ejecting seeds from the pod or fruit. The unequal tension of the pods of the common vetch (Vicia sativa) when drying causes the valves to contract unequally, and on a dry summer day the valves twist and pull in opposite directions until they suddenly snap apart, and the seeds are thrown forcibly for some distance. In the impatiens, or touch-me-not as it is better known, when the pods are ripe, often the least touch, or a pinch, or jar, sets the five valves free, they coil up suddenly, and the small seeds are thrown for several yards in all directions. During autumn, on dry days, the pods of the witch hazel contract unequally, and the valves are suddenly spread apart, and the seeds are hurled away.

Other plants have seeds provided with tufts of pappus, or hair-like masses, or wing-like outgrowths which serve to buoy them up as they

are whirled along, often miles away. In late spring or early summer the pods of the willow burst open, exposing the seeds, each with a tuft of white hairs making a mass of soft down. As the delicate hairs dry,

Fig. 482.

Touch-me-not (Impatiens fulva); side and front view of flower below; above unopened pod, and opening to scatter the seed.

they straighten out in a loose spreading tuft, which frees the individual seeds from the compact mass. Here they are caught by currents of air and float off singly or in small clouds.

895. The prickly lettuce.—In late summer or early autumn the seeds of the prickly lettuce (Lactuca scariola) are caught up from the roadsides by the winds, and carried to fields where they are unbidden as well as unwelcome guests. This plant is shown in fig. 483.

896. The wild lettuce.—A related species, the wild lettuce (Lactuca canadensis) occurs on roadsides and in the borders of fields, and is about one meter in height. The heads of small yellow or purple flowers are arranged in a loose or branching panicle. The flowers are rather inconspicuous, the rays projecting but little above the apex of the enveloping involucral bracts, which closely press together, forming a flower-head more or less flask-shaped.

At the time of flowering the involucral bracts spread somewhat at the apex, and the tips of the flowers are a little more prominent. As the flowers then wither, the bracts press closely together again and the head is closed. As the seeds ripen the bracts die, and in drying bend outward and downward, around the flower stem below, or they fall away. The seeds are

thus exposed. The dark brown achenes stand over the surface of the receptacle, each one tipped with the long slender beak of the ovary. The "pappus," which is so abundant in many of the plants belonging to the composite family, forms here a pencil-like tuft at the tip of this long beak. As the involucral bracts dry and curve downward, the pappus also dries, and in doing so bends downward and stands outward, bristling like the spokes of a small wheel. It is an interesting coincidence that this takes place simultaneously with the pappus of all the seeds of a head, so that the ends of the pappus bristles of adjoining seeds meet, forming a many-sided dome of a delicate and beautiful texture. This causes the beaks of the achenes to be crowded apart, and with the leverage thus brought to bear upon the achenes they are pried off the receptacle. They are thus in a position to be wafted away by the gentlest zephyr, and they go sailing away on the wind like a miniature parachute. As they come slowly to the ground the seed is thus carefully lowered first, so that it touches the ground in a position for the end which contains the root of the embryo to come in contact with the soil.

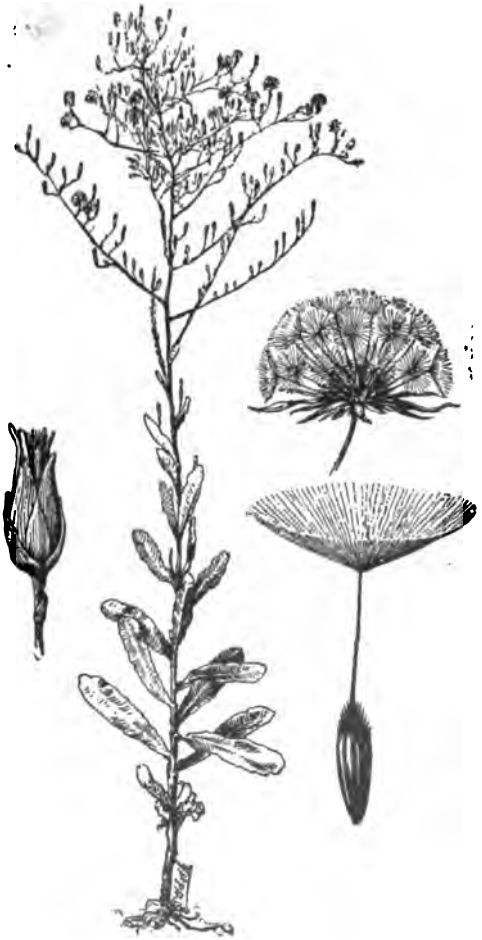


Fig. 483.
Lactuca scariola.

897. The milkweed, or silkweed.—The common milkweed, or silkweed (Asclepias cornuti), so abundant in rich grounds, is attractive not only

Fig. 484.
Milkweed (Asclepias cornuti); dissemination of seed.

because of the peculiar pendent flower clusters, but also for the beautiful floats with which it sends its seeds skyward, during a puff of wind, to finally lodge on the earth.

898. The large boat-shaped, tapering pods, in late autumn, are packed with oval, flattened, brownish seeds, which overlap each other in rows like shingles on a roof. These make a pretty picture as the pod in drying splits along the suture on the convex side, and exposes them to view. The silky tufts of numerous long, delicate white hairs on the inner end of each seed, in drying, bristle out, and thus lift the seeds out of their enclosure, where they are caught by the breeze and borne away often to a great distance, where they will germinate if conditions become favorable, and take their places as contestants in the battle for existence.

899. The virgin's bower.—The virgin's bower (Clematis virginiana), too, clambering over fence and shrub, makes a show of having transformed its

exquisite white flower clusters into grayish-white tufts, which scatter in the autumn gusts into hundreds of arrow-headed, spiral plumes. The achenes

Fig. 485.
Seed distribution of virgin's bower (clematis).

have plumose styles, and the spiral form of the plume gives a curious twist to the falling seed (fig. 485).

PART IV.

VEGETATION IN RELATION TO ENVIRONMENT.

CHAPTER XLVI.

FACTORS INFLUENCING VEGETATION TYPES; OR ECOLOGICAL FACTORS.

900. In studying the life and growth of plants it becomes very apparent that from the germination of the seed to the production of flowers and fruit the plant is dependent upon the favorable influence of certain conditions of environment. A dry seed kept in dry air or dry soil will never germinate, or if it is kept in moist soil, the temperature of which is below a certain minimum (from 6° C. to o° C.), it will remain apparently lifeless. But with a favorable amount of moisture and heat the life which was dormant becomes active, growth begins, the embryo is nourished by stored food, the root lays hold of the soil for support, and the stem and leaves rise to the light. Light now exercises an influence on the form and position of the leaves as well as on color and work. The root takes up watery food substances from the soil. If the soil contains too much water or too little, the plant suffers correspondingly; or if certain chemical substances are too abundant in the soil, or if others are lacking, the plant suffers. Still we know that some plants do better than others in wet soil or even in water of lakes or ponds, while still other plants thrive better in a comparatively dry soil. Some thrive better in rocky situations, some in sandy soil, some in mud, and others in humus.

Some thrive exposed to strong sunlight, others in the shade, and so on. Not only is the individual plant influenced by these conditions of environment, but colonies or societies of plants, as they exist in a natural state, which we call their home, are likewise influenced. In fact these conditions of environment largely determine the household relations of plants, i.e., the *ecological* relations, the study of which we call *ecology*, a study of plants in their home, or natural environment. These conditions are known as *ecological factors*. The ecological factors are in general of three sorts: 1st, physical factors; 2d, climatic factors; 3d, biotic factors. Some of the physical factors are water, heat, light, wind, chemical condition of the soil, physical or mechanical condition of the soil, etc. The climatic factors are rainfall and general atmospheric humidity, the broader temperature limits, great changes in temperature for long periods. The biotic factors are certain animals, the plants themselves, and even man.

I. Physical Factors.

901. Water. Importance of water.—Water is regarded as one of the most important of the ecological factors, though it should be borne in mind that no factor is operative unless certain other factors are also favorable. The plant responds only to the favorable action of several of the factors, and it is exceedingly difficult to ascribe a definite value to any one of them. We can study the influence of one by maintaining a certain degree of constancy of all the others. That water is a very important factor, however, can be seen from the fact that most plants contain a large percentage of water, which in the case of land plants is rapidly lost by transpiration, and must be replaced by absorption of more water from the soil, while in the case of water plants the effect of removing them for even a short while from the water and exposing them to dry air is easily seen.

902. A modicum of soil-water.—For all species there is a

physiological optimum as regards the necessary amount of water in the soil, or in all the environment, including moisture in the air. For many plants with which we are familiar the physiological optimum of water in the soil is when the soil is perceptibly moist, not dry to the feel, nor so wet as to be saturated, or so that water can be squeezed from it by pressure in the hand. These plants, which usually have thin leaves for rapid transpiration, if the water increases to the point of saturation in the soil, become sickly or die, because there is not sufficient air in the soil to enable the roots to absorb enough water. On the other hand, if the moisture in the soil diminishes, as during a dry period, the plant often wilts and even dies.

903. Very dry soil.—In regions where the soil is very dry for most of the year, the plants accustomed to an abundance of moisture will not grow. But here we find plants growing which through long time became accustomed to the conditions by being modified, i.e., the root system is enlarged, so there is more surface for absorption, while the leaf and stem system is reduced, so the leaves are small and thick, thus reducing the surface for transpiration, while at the same time providing a water storage in the thick leaves, succulent leaves, or tuberous roots.

904. Excess of soil-water.—Now if we turn to the situations where the soil is constantly saturated with water, or the ground is covered with shallow water, where plants accustomed to moist soil could not grow, we likewise find plants growing which have become modified so as to fit them to succeed under these conditions. The system of roots and root-hairs is reduced because of the water and unfavorable conditions for absorption, and correspondingly we find the leaf system usually reduced so that transpiration is lessened. In this way water in medium or scarce amounts, or in excess, exercises an influence on the plants. But the character of the plants cannot be determined alone by the amount of water in the soil. The humidity of the air, the drying effect of wind, the effect of heat and light, as well as the chemical and physical properties of the soil, are to be taken into account

905. Hydrodynamic forces.—There should be added also the hydrodynamic forces as a factor in influencing vegetation. The beating of the waves on rocks, or the force of the water at waterfalls, or in rapids, or flowing water, encourages a characteristic water flora, and water also assists in the distribution of seeds or plant parts. Of the greatest importance is the action of water in eroding the surface of the earth, resulting in the so-called levelling process; also the effect of floods and the cutting of the channels for streams. The mechanical effect of precipitation is sometimes injurious, especially in the case of hail, and in heavy snows which cling to branches and weight them down.

906. Light.—Light as an ecological factor influences plants in several ways: 1st. Influence of light in photosynthesis enables the plant to obtain the necessary carbohydrates. 2d. The influence of light in the direction of growth of stems and in the position assumed by leaves brings the plant organs in a position favorable for photosynthesis. 3d. In very many plants the leaves remain rudimentary unless they are in the light, and light in most cases is necessary for the formation of the green chlorophyll. Since some plants are able to outgrow other plants in their adjustment to the light relation, many of these, instead of dying out for want of brilliant illumination, have accommodated themselves to various degrees of intensity of diffused light, as in the case of shade plants and deep-water plants. Many shade plants are injured when subjected to direct sunlight, so that light as well as water is harmful to certain plants under certain conditions, and its modifying influence is therefore greater in plant forms than it otherwise would be. An abundance of light is usually necessary for development of flowers and fruit. Light also accelerates transpiration, and is thus of direct benefit to the plant when supplied with an optimum of soil moisture, and injuries sometimes result to plants when root absorption is active and transpiration is slow. Leaves exposed to direct sunlight have a thicker epidermis than shade leaves, and in the latter the palisade layer of cells is less developed and the leaves are thinner and softer.

907. Heat.—Heat has a great influence on plant growth and distribution, as well as upon the general form of much of the earth's vegetation.

908. Vegetation at low temperatures.—Many arctic and alpine plants are able to vegetate and even fruit at extremely low temperatures, some of them very near to zero centigrade. Some arctic algæ fruit in the dark at 1.8° C., while many arctic plants can exist at −50° to −70° C. Spores of some fungi, bacteria, and algæ, and certain dry seeds, can endure much lower temperatures. The growth period for most vegetation begins at about 6° C. (=43° F.), or in the tropics at 10°–12° C., while often a much higher temperature is necessary for reproduction of many plants. Among the flowering plants annuals are largely excluded from polar lands, because the summer season is so short that the total available heat is not sufficient for growth and reproduction. Annuals need a longer time for this than perennials. The upper limit of temperature favorable for plants in general is 45°–50° C., while the optimum is below this.

909. Very high temperatures, however, are injurious if not fatal to most plants, though certain algæ are known to vegetate at 80°–90° C. Some desert plants are able to resist a temperature of 70° C., while some flowering plants are killed at 45°. Where plants or their seeds or spores contain a large percentage of water, they are more easily killed by high degrees of heat or low degrees of cold. But dry seeds and spores are often very resistant. Some air-dry seeds will resist a temperature of 120°–130° C. Spores of certain bacteria will resist a temperature of 130° C. for a short time, while at a temperature of 100°–110° they may live for several hours. But if allowed to germinate and thus pass into the vegetative condition in which they contain much more water, and the protoplasm is in a less resistant condition, they are killed at 100° in a short time, or even at 80° continued longer.

910. Cardinal temperature points for different plant functions.—It has been found in the case of many plants that for the different life functions, or separate processes in growth and

reproduction, the temperature which is most favorable varies in the different processes. For each process there is a minimum, optimum, and maximum temperature, the minimum and maximum representing the lowest and highest temperatures at which the process can take place, while the optimum is the temperature most favorable for the process. The *absolute* optimum, which corresponds to the highest intensity of a function, therefore is not always the most favorable temperature for the plant as a whole. For in the case of transpiration and respiration at the absolute optimum temperature these processes would take place so rapidly that the plant would be injured. On the other hand, the *harmonic* optimum corresponds to the most favorable intensity of a function. So the "ecological optimum is composed of the harmonic optima." The cardinal temperature points are the most favorable temperatures for the various processes. From germination of the seed through growth and reproduction there is a general rise of the curve which represents the cardinal points for the various processes, but there is a more or less regular fluctuation or alternation of the successive cardinal points; especially is this the case with many plants in temperate and arctic regions. For example, the cardinal point for the growth function is often higher than the cardinal point for flower formation and reproduction.

911. Acclimatization.—When plants are changed from warm zones to colder ones, or from cold zones to warmer ones, either by man or by the laws of migration, if they are able to reproduce and propagate themselves in the new region it is because they have become adapted to the changed conditions of temperature. This adaptation of an organism to changed climatic conditions is called *acclimatization*. Acclimatization to changed temperature conditions is possible in the case of those plants which are able to adjust the cardinal points for the different life processes to the new temperatures. This is accomplished by raising or lowering the cardinal points for the different functions. It is a well-known fact that some plants taken from cool zones to warmer ones are able to raise the cardinal points for processes of nutri-

tion, assimilation, and growth, so that growth is much more luxuriant than in the cooler climate, but they fail to flower or seed because they are not able to raise the cardinal point for these processes. Such plants become acclimatized with reference to certain functions only. So some plants taken from warm climates to cooler ones may grow well, but fail to flower or fruit because they cannot lower the cardinal temperature-point for these functions to meet the new conditions. Different species vary in this respect. The same species also may possess the power of raising or lowering the cardinal points of all its functions to a remarkable degree, and this probably accounts for the very wide north-and-south distribution of certain species.

912. Protection against cold.—Intense cold prevents root absorption, and has a drying effect on vegetation, so that vegetation protects itself in several ways through the severe winter in temperate and arctic climates. The deciduous habit of trees and shrubs, the underground stem of perennial herbs, the rosette habit of perennials, the bud-scales on winter shoots, and the low stature of arctic and alpine plants are modifications in response to the harmful effects of extreme cold.

913. Effects of freezing.—In freezing weather plants are injured in three ways: 1st. The chilling effect of cold is sufficient to kill some plants which are very sensitive to low temperatures. 2d. Others are killed even by comparatively light frosts, or freezes (examples: potatoes, tomatoes, corn, many herbs, young leaves and shoots of many plants). In these cases the injury is chiefly caused by the loss of water from the protoplasm in the cells. As freezing takes place in the tissues the ice crystals are usually not formed within the cells. But some of the water, under the influence of the extreme cold, is gradually withdrawn from the cells into the intercellular spaces where the ice crystals are gradually formed. This is in reality a protection to the protoplasm, since it becomes "drier" and thus more resistant to cold. When the plants "thaw" out, if the protoplasm has not been killed by the cold, this water may be absorbed by the protoplasm again. and the plant is not injured. Freezing, then, to a

certain extent has the same effect on the protoplasm as the loss of too much water by transpiration. The bud-scales thus prevent the loss of too much water from the cells of the delicate tissues of the growing point of shoots in winter, although in many cases freezing in these tissues takes place. 3d. In other cases plants are killed by the actual freezing of the protoplasm, though there are some plants which are not killed by freezing of the water in the protoplasm. The ability of some plants to resist this is probably specific.

914. Wind.—The effects of wind on vegetation are manifest in several ways for harm or for good. Severe, frequent, and long-continued winds stunt and deform trees and shrubs, and destroy or reduce the size of herbs. Winds also have a drying effect, and this is probably one of the reasons why forests are not developed on much of the prairie regions. Every now and then in normally humid climates we have an illustration of the blighting effect of dry winds on vegetation. "Sand blast," i.e., sand driven by the wind is very injurious to vegetation in sandy areas where there are high winds, tearing the leaves and even eroding the shoots. On the other hand wind is one of the great agencies for pollination, especially in the case of anemophilous plants, and it is one of the important agencies for seed distribution.

Fig. 486.
Main trunk straight, branches all bent and fixed to one side by wind from one direction (Rocky Mountains).

915. Ground covers.—Plants are protected by the covering of the ground in various ways. Among the lifeless covers may be mentioned the following:

916. Snow cover.—Snow protects plants during the winter by checking radiation of heat from the soil so that the ground does not freeze, or freezes to a less depth. For trees and shrubs this is an advantage, since root absorption is permitted to some extent, sufficient often to supply water to the plant which is lost by evaporation from the branches or the leaves of evergreens. In arctic and alpine regions the entire vegetation is often covered and transpiration thus checked in the cold dry atmosphere. In

Fig. 487.
Snow covering showing protection of low vegetation in winter.

these regions trees and shrubs are often deformed or laid prostrate by the weight of snow, so that it exercises a dwarfing influence. That snow protects trees and shrubs from dying by covering them up is shown by the fact that in arctic regions branches and stems projecting above the snow die because they dry out. In temperate regions perennial plants, like grass, some fall crops, etc., are protected during the winter by snow cover, since a more equable temperature is maintained and transpiration lessened. Where the ground is bare in the winter the alternate thawing and freezing of the surface "heaves" the ground and lifts the roots from the soil. Snow also conserves moisture and distributes snow-water during the warm season in mountain regions over a longer period, especially where the sun does not

have such a direct action on it. Snow and ice also, in the form of glaciers, destroy vegetation, and on the other hand grind up rocks and assist in soil formation.

917. Leaves and other plant remains form a mulch or protection cover, which is especially abundant in the forest. This protects the roots from extreme cold, lessens radiation, conserves moisture, etc.

918. Living plant covers.—The highest development of cover by living plants is seen in the forest, and the result is shown in the development of shade plants which are protected from excessive light and heat, while the air of the forest is more humid. The under plants in a forest are also provided with better protection from cold. The water from rainfall is conserved, and the snow melts more slowly, thus giving a more uniform distribution of water throughout the season and lessening the danger from freshets and floods. The cushions or carpets of moss, formed in some places, conserve moisture. They take little moisture from the ground, since the moss cushion acts something like a sponge to absorb and hold water from rainfall or from atmospheric moisture.

919. Chemical conditions of the ground or water.—*Chemical constituents of soil.* The chemical constituents of the soil are derived from several sources, especially from solutions of eroded and dissolved rock formations, from the decaying animal and plant remains, from certain gases taken in solution in rain-water, from salts of sea-water, etc. Since the geological formations of the earth differ in their constituents, and the bulk and kinds of plants and animal remains differ, and also since forces of erosion and decay, and so on, vary according to certain conditions, the soil varies greatly over the face of the earth and even over small areas. According to investigations on certain of the higher plants, ten elements are necessary for most plant growth, as follows: oxygen, hydrogen, carbon, nitrogen, phosphorus, sulphur, iron, potassium, calcium, and magnesium. If any one of these is lacking in suitable quantity, the plants become sickly. For most green plants, most of the carbon and much of the

oxygen come from the CO_2 of the air, while the other substances are in solution in the soil, or in certain compounds, or are brought into solution by the plant, or in the case of nitrogen it is sometimes fixed from the air by microscopic plants and made available for plant food. There are other substances also in solution in the soil, and plants often absorb certain substances which are not needed for food, and sometimes substances which are harmful.

920. Effect on plants.—Whenever one or more of these elements are in excess in the soil, or where harmful substances are in solution in perceptible quantities, the vegetation responds by changes, by varying in vigor of growth, or a varying ratio between growth and reproduction, or by a modification of the habit, form, structure, and function. The most marked modifications induced by chemical conditions of the soil are in the case of the alkaline or salt basins, the excess of salt interfering with root-absorption, resulting in a modification of stem and leaf by reduction of transpiration surface, and increase of water-storage tissue. Similar modifications also take place in plants growing in peat moors, where there is an abundance of humus acid in the soil. Soils with an abundance of lime also influence certain vegetation, modifying in some cases certain species so that they take an alpine form. The chemical condition of the soil is directly related to the plant's ability to absorb water. The roots of plants will absorb more water when pure than when it is in solution. For absorbing nutrient salts for every plant there is a most favorable concentration, above which they take up water with difficulty. (The concentration of the solution which plants can take up rarely exceeds 3 per cent, and in most land plants is far below this.) Different kinds of salt solutions affect in a different degree the absorption activity of the plant, for example, sodium chloride (table salt) acts more energetically in retarding absorption than sodium nitrate (saltpeter). Mixing of different salts acts more energetically than a single salt.

The mineral substances in the soil, as nitrates, phosphates, sulphates, lime, potash, magnesium, and iron oxide, are impor-

tant, not only because of the effect they have upon the physical condition of the soil, but also because of their activity in the various metabolic processes in the plant. Some enter into the production of protoplasm, some play a secondary part in stimulating certain processes or activities of the plant.

Within certain limits plants adapt themselves to changes in the chemical condition of the soil, or to chemically different soils, but there is great variation in this respect in different species. To a nutriment salt like sodium nitrate in the soil, plants will adapt themselves more readily to an increase in the concentration, than to a non-nutrient salt like sodium chloride. But when the concentration of the salt goes beyond a certain grade, according to the species, it acts as a poison.

921. Physical condition of soil.—Rocky regions are least suited for vegetation, except under certain conditions, and with a limited number of plants. In mountain regions, large areas of rock may be bare of vegetation, especially if the rock lacks crevices. In the drier situations the vegetation may be limited to rude lichens, or a few of the lower algæ in moist situations. Along the sea-coast, where the rocks are washed by wave action, certain of the large marine algæ are enabled to obtain a foothold by means of holdfasts, even on the smooth surface of rocks.

Where the rocks are creviced, there is an opportunity for foothold for a greater variety of plants, mosses, ferns, and the flowering plants. The crevices also serve to catch and retain the disintegrating remains of lichens and other vegetation which mingle with the crumbling portions of rock, and form a different soil which provides food for a greater variety of plants. Where the rock is more broken in the form of boulders or small stones, the more exposed surfaces harbor lichens, while the interstices give an opportunity for the accumulation of a greater mass of finer soil. Where the rock is reduced to gravel or coarse sand, the disintegrating vegetation eventually mixes with and covers it, offering a still wider range for plant growth. With the weathering and crumbling of the rocks, the admixture of decay-

ing vegetation, and the action of certain chemical solvents on certain rocks, the finer and less porous soils are formed. The variation in the proportion of these ingredients together with the different degrees of disintegration of vegetable matter make the soils of different physical conditions.

922. Relation of physical condition of soil to plant growth.— The relation of these different physical conditions of soil to plant growth lies in the means it affords the plant to get and maintain a foothold, its power of absorption and retention of water, the circulation of air, the ability with which the soil particles hold mineral substances necessary for plant food, its power to absorb or radiate heat, to reflect or absorb light, its tenacity or power of resistance to washing by heavy rains, or drifting in winds, etc. Thus the soils of a region having the same annual rainfall vary in their capacity to hold water, so that one kind of soil may have a vegetation which is largely xerophytic (see Chapter XLVII); for example, fine ground lime soil poor in humus, because of its low water-holding power, while on lime soil rich in humus a mesophytic or hydrophytic vegetation may thrive. Sand has a less water capacity than clay, and also parts with it much more readily by evaporation. A fine-grained soil, rich in humus, is most favorable for the retention of a suitable amount of moisture. Forests and meadows here reach their highest development. Sandy soil poor in humus underlaid with gravel becomes wet with each rain, but quickly dries out. Clay surpasses all soils in its power to take up and retain water. According to Schimper, clay grounds in the dry regions of the Mediterranean are highly prized because of this power to absorb and hold water, while in west Europe where the precipitation is great, the clay soils are often too wet. In this condition, clay soils, as well as lime soils rich in humus, are apt to lack oxygen because of their non-porous condition, and are, therefore, unfavorable for plant growth.

923. The chemical condition of the soil often affects its physical properties, so that clay is made less porous by adding potash, ammonia, etc., or more porous by the addition of certain acid salts, phosphoric acid, etc.

II. Climatic Factors.

924. Rainfall, or precipitation.—This factor has a close relation to the water factor, but still its effect in general is climatic. Rainfall is one of the most important elements determining the plant population of a region. The luxuriance of vegetation and the number of individuals of a kind, other things being equal, is in direct relation to the percentage of rainfall over different parts of the earth's land surface. Rainfall depends on currents of moisture-laden air from warm bodies of water sweeping over cooler areas of water or land, or more rarely, on currents of cool air passing over warm areas covered with a moisture-laden atmosphere. According to scarcity or abundance of rainfall the earth may be mapped into areas of rich vegetation, largely forest areas; into plains or steppes; prairies; and deserts (see Chapter XLIX). It will be well to note here briefly the rainfall or precipitation in different parts of the earth.

925. In North America, a narrow belt along the Pacific in Oregon and Washington, the rainfall is more than 60 inches annually. In some places in Washington State it is more than 100 inches. This is due to the moisture-laden winds from the warm waters of the Pacific Ocean coming in contact with the cooler air of the land. In Florida there are similar abundant rains, owing to the warm winds from the tropical seas. For the same reason the annual rainfall in the Gulf and Atlantic States is in general more than 50 inches. The luxuriance of vegetation in some parts of Florida and Washington is found where the rainfall is so great.

926. The great arid region of the United States.—There is a district in Nevada, southern California, and Arizona where the annual rainfall is less than 5 inches, while in most of Nevada and Utah, parts of Arizona, New Mexico, Colorado, and Wyoming it is below 10 inches. The Sonora-Nevada Desert is located in this region. A wider belt extends from middle Oregon far into Nebraska and South Dakota, where the precipitation is less than 20 inches. The warm moisture-laden winds of the Pacific lose a large part of their moisture near the coast, move eastward over the Rocky Mountains, and furnish comparatively little rainfall from middle Oregon eastward. The Rocky Mountains, being so high and cold, cause a greater precipitation of the small amount of moisture remaining in the air than occurs on other plateaus (Gilbert and Brigham, Introduction, Phys. Geog.). The northern Mississippi region receives a medium amount of rain from the diminishing moisture-laden atmosphere from

the Gulf and Middle Atlantic, yet it is still sufficient to support an abundance of plant life. Thus it is seen that in general the interior of continents is drier than the coast regions.

927. In southern California, Lower California, and northern Mexico the arid region extends to the Pacific, since the warmth of the land is not sufficient to cause precipitation of the cooler air at this point.

928. In Central America, northern, central, and eastern parts of South America, the rainfall is very great. This constitutes the humid tropical region of the western continents, which is noted for the luxuriance of its vegetation. In much of the Amazon country the rainfall is over 80 inches. The prevailing winds are here from the very warmest part of the Atlantic Ocean, which explains the exceptional precipitation in this continental interior. West of the Andes mountain range it is dry.

929. In Great Britain the warm Atlantic currents furnish warm, moist winds which on the west coast give a precipitation of about 40 inches, while in the cooler highlands it reaches 60 to 80 inches, and falls to 25 to 30 inches on the east coast. The latter is low for plants, but is ample in such a cool climate as that of England. In southern Europe the rainfall is gradually less toward the interior of the continent.

930. Much of Russia and Siberia is arid, especially northeast Russia (the interior from east to west). The prevailing winds are from the cold Arctic Ocean, which passing over a warmer land area, the moisture is only slightly precipitated. In southern Siberia there is moderate rainfall.

931. India and Burma are furnished with a high annual rainfall because of their relation to the warm Indian Ocean to the south, from which the prevailing winds sweep with great force from the southwest and are called *monsoons*. These produce great rains over southern Asia to the Himalaya Mountains, at which point most of the moisture has been precipitated. In the delta region of the Ganges River the monsoon winds from the Indian Ocean yield the highest precipitation, the annual rainfall being over 500 inches, or in one year over 800 inches, equals 67 feet. The luxuriance of the vegetation of southern Asia is well known. On the other hand, the high plains of Tibet and Central Asia just beyond the Himalayas are arid, and have a desert vegetation.

932. In eastern Asia there is a plentiful rainfall. In Japan the rainy season extends from April to September, and at Tokio the annual rainfall is about 58 inches. In Korea it is 36 inches. Hongkong, farther south, has a rainfall of 78 inches, while in the Philippine Islands and Dutch East Indies the winds coming from the warm parts of the Pacific produce great rainfall.

93 . In Australia in the central west the precipitation is less than 5 inches; in the lower part of the interior it is about 10 inches; but is heavier toward the east coast and over a small area on the southwest coast.

934. In the Sahara Desert the winds come mainly from the cool Mediterranean at the north, so that there is little or no precipitation.

935. Temperature.—Besides the physical effects of heat, heat is to be considered as a climatic factor. The amount of heat during the period of growth and reproduction has a very important bearing on the limits of plant distribution. Plants vary in their total heat requirement, so they are drawn into broad climatic zones, from polar lands to the equator and also more or less parallel with mountain chains. Ocean currents affect the climate, and also deflect these life zones, as they are called (see Chapter XLVIII). "Glacial" epochs also profoundly influenced the vegetation of the earth, since the southward extension of the cold wave was so great as to destroy plant life over large regions, and cause a general southward shifting of the life zones which moved northward again as the glaciers retreated (see Chapter XLVIII).

936. Physiography.—The physiography of the earth's surface exerts a powerful influence upon vegetation. Mountain chains, oceans, rivers, etc., present barriers to plant migration. They also produce lines of tension or stress between them and adjacent territory. Rivers also act as conductive agencies. On mountain sides lines of stress are also produced because of difference in altitude, and consequently difference in temperature, so that a zonal arrangement of vegetation results. Thus the life zones which are in general transcontinental are deflected far to the south or north because of variations in temperature accompanying variations in altitude, or influenced by the different ocean currents. In hilly countries, as well as in mountains, exposure to light, the sun's heat, etc., affects vegetation, while the undulating surface is one of the factors in determining the water content of the soil.

III. Biotic Factors.

937. Factors for pollination and distribution.—Some of the biotic factors have been discussed in other places. The agency of insects in pollination, in the case of entomophilous flowers in Chapter XLIII, has a great influence in increasing the fertility and

vigor of many plants. Birds and other animals aid in distribution by eating fruit and seeds, many of the seeds being evacuated unharmed, while in some seeds their germinating power is increased by passage through the alimentary canal of animals. Squirrels bury nuts, many of which are forgotten, and are thus in a condition to germinate. Some animals carry in their hair or fur seeds which are provided with grappling appendages. The various mechanical adaptations for pollination and seed distribution, the various means for protection, might also be mentioned.

938. Factors changing the soil.—Burrowing animals bring about a rude sort of accidental culture, perhaps giving rise in the past to certain weed types. Certain ants cultivate grains for food. Of the greatest importance to vegetation is the burrowing work of earthworms, since they loosen up heavy soils, permit access of air, of humus, and often make it possible for roots to penetrate into compact soils. When they come to the surface their earthy excrement covers leaves and assists in decay, while the alkaline excretions of their bodies neutralize to some extent the humic acid in the woods. Man in his cultural operations has profoundly changed the face of nature,—produces immense crops of certain useful plants, and, by taking advantage of a knowledge of laws of evolution, is turning his attention to guiding evolution of more useful plants.

939. The active factor in plants.—Plants themselves are important biotic factors influencing vegetation. The shade of the forest, or of other layered plant societies, protects vast numbers of plants, gives protection to vast numbers of climbers, epiphytes, etc., while all are apt to harbor parasites when living, but certainly are the prey of the scavenger members when dead. These immensely important members of all plant societies reduce dead vegetation to humus, and eventually to a condition in which it is again available for food for the higher plants. In this phase of the work the lower organisms often join forces with the roots of the higher plants in symbiosis or mutualism. Then there are the bacteria which fix nitrogen, the legume tubercle organism,

the nitrate and nitrite bacteria, etc., which prepare food for the higher plants.

940. The responsive factor in plants.—The power which the plant possesses to relate itself to environment, and to undergo slight changes in form, texture, etc., which adapt it better to

Fig. 487*a*.
Willow trees pollarded by man

different conditions, is a most important factor. This is shown in the power of growth and response to environment in the assumption of favorable positions by its different parts from the seedling stage onward. This response of plants to environment is further manifested in the diurnal and nocturnal movement of leaves, the nutation of stems, etc.

CHAPTER XLVII.

VEGETATION TYPES AND STRUCTURES.

941. By vegetation type is meant the form and character of vegetation elements under special conditions of environment. We are concerned primarily with a study of the plant form as related to environment, not with a study of floral elements or plant relationships. Species which are not at all closely related from a taxonomic standpoint may be of the same vegetation type.

942. The responsive type of vegetation.—By this is meant the reaction of vegetation to environment, the response of the plant in adapting itself to its environment. Within certain limits many plants will respond in a single season to a change of environment and will assume a form of leaf and stem which fits them to better endure the unfavorable conditions. This, however, takes place where the change is not very great, or in case of certain plants which have a wide range of adaptability. Vegetation types have been developed by gradual change through long periods of time. Some of the striking vegetation types are those of desert plants, those growing in sandy areas in moist climates, or where the soil is very alkaline and interferes with absorption. The types found in these situations are similar, since the plants obtain water with difficulty from the soil, and so their aerial parts in response to this take on a form which enables them to conserve water. There are several different classifications of vegetation types. Two of these, proposed by Warming and Schim-

per, will be presented here. These vegetation types are classified into societies as follows:

I. Warming's Vegetation Types.

943. Mesophytes.—These are represented by land plants under temperate or medium climatic and soil conditions. The north temperate regions (with the exception of mountain heights, the arid regions, the sand-dune areas, etc.) are most favorable for the development of the mesophyte type. The normal land vegetation of our temperate region is composed of mesophytes; example, the deciduous forests or thickets of trees and shrubs with their undergrowth, the meadows, pastures, and prairies. Mesophytes occur, however, in arctic regions; for example, the low-growing mats of grass, or herbaceous vegetation which appears during the summer months. The rainy-season flora of the deserts or plains also forms mesophytic societies. The land of these regions, however, is not populated by mesophytes alone. There are many xerophytic plants growing in mesophytic societies; for example, the conifers in the "mixed" forests are xerophytes, and make the characteristic xerophytic society of subarctic or subalpine regions. There are many other examples of xerophytic plants growing in mesophytic societies, as the purslane (Portulaca), the stonecrops (Sedum), some of the cacti, etc.

944. Xerophytes.—Plants growing in very dry regions, or under conditions of environment where absorption of water by the roots is difficult, or such as to favor the loss of water from the aerial organs in excessive amounts for long periods, are known as xerophytes. A plant having a habit or structure which fits it to live under these extreme conditions is a *xerophyte.* The most characteristic xerophytic plants are the perennials which inhabit the desert. Less highly specialized xerophytes are those which grow in subarctic or alpine regions, or in rocky places or on sand-dunes. In the deserts especially, xerophytic plants are developed to the exclusion of others, except in certain specially favored localities, and excepting also the rainy-season

flora. In subarctic and alpine regions, as well as in rocky places or in sand-hills, mesophytic plants are often intermingled, because the conditions of environment are not so austere. Xerophytic situations are as follows:

1. Deserts, sand and gravel hills, sand-dunes, rocky places, steppes and some prairies, high arctic and alpine districts.

2. Soils or waters with large quantities of acids (as humic acid in certain marshes or woods), or of salts (brackish or salt marshes or bodies of water, and alkaline soils).

945. Hydrophytes.—Plants growing in "fresh" water, or in land where the soil is very wet, or the air very humid throughout the season, are *hydrophytes*. They have a water environment, or one in which the air is so moist that loss of water from the aerial organs is hindered. The leaves, and often the stems, even of land hydrophytes, are soft and watery. They favor rapid loss of water, but the moist environment checks the too rapid transpiration.

946. Halophytes.—It is customary to restrict the term *hydrophytes* to plants growing in bodies of "fresh" water. Plants in salt or brackish water are *halophytes*. Halophytes differ from hydrophytes in the fact that the protoplasm of the former has a higher osmotic tension than the latter. Halophytes are therefore enabled to live in saline water and to absorb liquid food from the same. The usual hydrophytes, placed in the same environment, would collapse, because not only could they not absorb water, they would lose their turgor and collapse because of the higher osmotic tension of the water environment. Those halophytes which are rooted in soil saturated or covered with salt water (salt-marsh plants), and have aerial organs for transpiration, have a xerophytic habit so far as their leaves or aerial parts are concerned. In fact they are by some classed with xerophytes. This is because the salinity of the water retards root absorption, and, in correlation with this, the aerial parts have taken on a xerophytic habit in order to retard transpiration. Halophytes, however, which are habitually immersed in water, as the seaweeds for example, cannot be considered as xerophytes.

II. Schimper's Vegetation Types.

947. Another general classification of plants as regards their adaptation to environment is that proposed by Schimper. There are three kinds:

1. *Hygrophytes*, which are especially provided with structures favoring the loss of water, and which usually live under conditions in which the danger of desiccation is excluded.

2. *Xerophytes*, or dry-conditioned plants, which exist under conditions which necessitate specialized structures for conserving water and for retarding transpiration. .

3. *Tropophytes*.—These are plants which correspond nearly with the mesophytes of the former classification. They show a remarkable adaptation to extreme conditions, and represent the highest physiological type of temperate-region plants.

948. Tropophytes. — Several types of tropophytes are recognized.

1. *Deciduous trees and shrubs.* — Through the growing season these plants bear foliage. The transpiration stream is strong, root absorption is active, and transpiration is abundant. The plants in this condition are mesophytes, and their life relations are temperate. With the approach of winter they shed their leaves and thus *turn*

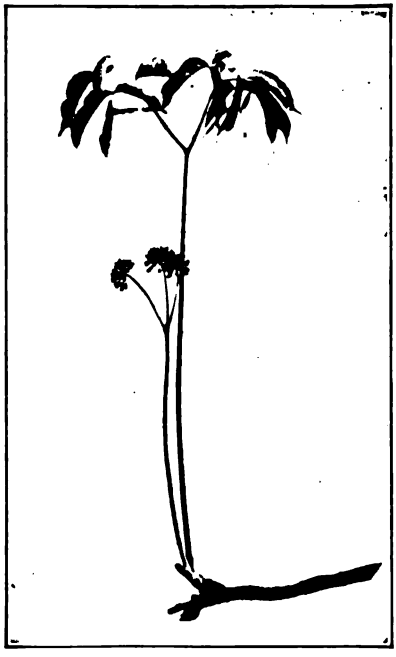


Fig. 488.
Perennial plant (Aralia nudicaulis) with a subterranean rootstock, and annual leaf and flower shoot.

from a mesophytic to a xerophytic habit. If the usual broad-leaved trees and shrubs retained their green living leaves through the winter, the loss of water would be so great as to kill the trees. The soil being so cold, root absorption is at a very low ebb, or often ceases for considerable periods. By discarding their leaves, transpiration is greatly lessened, and the life of the tree or shrub is preserved.

2. *Perennial herbaceous plants.*—In these plants the aerial shoots as well as the leaves usually die on the approach of winter, while the underground shoot, in the form of a bulb, tuber, rhizome, or simple shoot-stem, is protected from drying out by its covering of soil or leaf-mold. These plants are sometimes termed *glophilous*, because they are dependent on the subterranean parts for preservation through the winter.

3. *The annuals and biennials* might be treated of as a third type of tropophytes. In the annuals the plant lives only through the growing season, and on the approach of winter, or of the period when extreme xerophytic conditions prevail, *turns* to seed. The seed is the xerophytic stage of the plant. Biennials might even be made a fourth type, the underground stem being developed the first year, exists through the winter, and the second year the plant forms seed.

III. Plant Structures Adapted to Conditions of Environment.

949. The normal plant condition.—Theoretically the normal plant condition is one in which the plant lives under uniform conditions of environment throughout the year, with slight fluctuations of temperature, humidity of the air, etc. These conditions are more nearly approximated in humid tropical countries. Temperature and moisture conditions, both of soil and air, are relatively high and uniform. These conditions favor luxuriant vegetation, which is characteristic of the humid tropics. Many tropical plants, like the palms, are evergreen, because they hold their leaves for more than one year. But

many other tropical plants are deciduous, casting their leaves simultaneously, and in a few days new leaves are put forth. There are no periodic extremes which require xerophytic structures for a season. Under these normal static conditions for plant growth, we would expect a luxuriant development and a vast overproduction with a tendency to migrate outward into subtropic and temperate regions, during which modifications are slowly brought about in the evolution of species adapted to different conditions. Under these normal uniform conditions the plant develops an extensive foliage surface adapted to transpiration, which is not likely to become excessive because of the high degree of humidity of the air as well as the abundant precipitation.

950. Xerophytic structures.—The physical factors which determine the conditions for xerophytic vegetation are of two kinds:

1. *Those which decrease the water supply to the plant*, or make it very limited, as slight precipitation, porous soil of a texture which does not readily hold water, lack of subterranean supply, or "ground water," strong winds or continual sunshine, which dry out the soil, low temperature, thin soil covering on rock subsoil, thin mulching of vegetation, steepness of slope which admits of rapid removal of water.

2. *Those which accelerate the loss of water* from the plant, as dry air, high winds, high temperature if accompanied by dryness of air, low atmospheric pressure, intense illumination, absence of tall vegetation which affords protection to shade plants.

In the adaptation of plants to dry conditions modifications have taken place along many different lines. These modifications are all designed for the same purpose, to conserve water for the plant, to increase absorption by the roots, and to decrease transpiration by the aerial parts.

951. Lessened transpiration.—This is brought about in the case of xerophytic plants in four general ways:

1. *Reduction of leaf surface.*—This is usually accompanied by a thickening of the leaf, so that for the same mass of leaf sub-

stance there is a less surface for transpiration. The needle-like or awl-shaped leaves of the conifers, junipers, etc., are examples of xerophytic structures adapted to lessen transpiration. The leaves of yuccas, while quite large, are very narrow and pointed in proportion to the mass of the leaf. This kind of leaf is characteristic of many plants of deserts or permanently arid regions. Examples need not be multiplied here; some are mentioned under the general treatment of leaves (Chapter XL), and others in treating of desert, arctic, heath, salt-marsh, and other societies. Periodic and complete reduction of leaf surface takes place in tropophytic plants in preparing them for the xerophytic stage in which they pass the winter (see paragraph 938).

2. *By protective covering or movements.*—Protective coverings in the form of hairs, scales, a more or less thickened cuticle, thickening of the epidermal wall, or a doubling of the epidermal layers retard the loss of water. Protective movements of leaves also take place in some plants, which tends to lessen transpiration. A slight loss of turgor often causes leaves to droop and assume a position in which transpiration is lessened. Remarkable movements of leaves take place in the so-called sensitive plants, belonging to the acacias and mimosas. These are highly developed in arid regions. When the loss of water passes the optimum, the leaflets fold together, or the whole leaf droops and brings the leaflets in close approximation which retards transpiration. The leaves of many grasses become rolled up and thus lessen the loss of water. The leaves of the evergreen rhododendrons roll up in a striking way when the loss of water becomes excessive in drought, but especially in very cold weather.

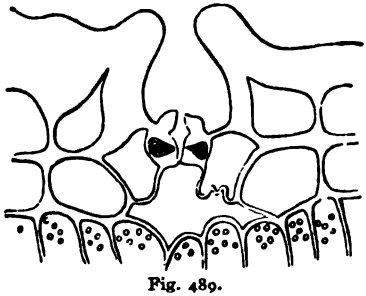


Fig. 489.
Deeply sunken stoma of Franklandia fucifolia. (After Schimper.)

3. *Action and position of the stomata.*—The work of the stomata in regulating transpira-

tion has been described (paragraph 84). In many xerophytic plants, especially in arid regions, the stomata are sunk in deep cavities in the leaf so that the loss of water from them is not so rapid. In many cases several of the above types of means for retarding the loss of water from leaves are combined.

4. *Total absence of foliage leaves.*—This is a striking peculiarity of many desert plants, or plants of very arid regions, for example the cacti. Even in regions where mesophytes and hydrophytes grow there are examples of plants devoid of leaves, as seen in the horsetails and in many of the rushes.

5. *Thorns and spines.*—With the reduction of leaves there often occurs a development of thorns and spines, especially in dry situations. These often accompany reduced leaves on the same plant, while in the cacti the spines often take the position of leaves.

6. *Water reservoirs.*—In some plants the power of holding considerable amounts of water in their tissues is very marked. Such parts of the plant are real reservoirs for water storage. It is a marked feature of the plants called succulents. In the thick stems and leaves of the purslane (Portulaca) the middle portion is largely devoted to the storage of water. The same is true in the thick leaves of the stonecrops (Sedum). In some begonias a layer of cells just underneath the epidermis of the leaves serves as a water reservoir. Such plants when growing under moderate climatic conditions have little need of water storage. But when they inhabit alkaline or saline soils, or soils in dry regions as they sometimes do, this habit stands them in good stead. One can easily demonstrate their power of retaining water in dry weather by pulling up the plants and leaving them on the ground or by hanging them on the fence. They remain fresh for a long time, while the ordinary plants quickly wilt. It is readily seen from this how they are enabled to retain life in dry situations during long periods, since they dole out the water in small quantities. The most remarkable examples of the power of plants to retain water are found in the cacti, where immense trunks with no leaves, and a limited surface exposed to the air

in comparison with the bulk of the plant, enable the plant to resist long periods of excessive drought. In fact it is very difficult to dry out the stems of some of these plants provided with water storage.

952. Hydrophytic structures.—From what we know of the life of plants on the dry land it is evident that water plants have some very different problems to solve in their life processes. Some of these adaptations in structure are as follows:

1. Provision for attachment.
2. Provision for floating.
3. Provision for aeration.
4. Provision for distribution of food.
5. Provision for fruiting.
6. Provision for protection from water movements.

1. *Provision for attachment.*—In most of the aquatic flowering plants and ferns attachment to the ground is accomplished as in the case of land plants by roots. The roots here serve chiefly as holdfasts, since there is only a slight development of root-hairs or none at all in the case of submerged plants anchored in the soil or rock crevices. Where the entire plant body or a large part of it is immersed in water, absorption takes place through the surfaces in touch with the water. The development of vascular bundles is weak or wanting, since it is not necessary for the plant to distribute water from the root system. See note, p. 712.

2. *Provision for floating.*—This is provided for by large intercellular spaces which contain air or other gases. The air-spaces in some stems and leaves are much greater than the bulk of the tissues themselves, and serve to buoy up the plant. In the case of many plants like the potamogetons, where the leaves are entirely submerged, or some of them float on the surface of the water, the stems are slender and pliant, and do not possess strengthening tissues sufficient for support. The more or less upright position of the stems is due to the floating power afforded by the numerous large air-spaces. Oxygen given off by some filamentous algæ in the process of photosynthesis becomes caught between the threads in a tangle and floats the plant on the sur-

face. Some of the blue-green algæ develop on the mud in the bottom of pools, and the accumulation of gases in the tangle later buoys them up to the surface of the water.

3. *Provision for aeration.*—Aeration is provided for through the abundant air-spaces in the more bulky stems and leaves, and also by the ability of many plants to float to the surface where the threads of algæ are, or near the surface, or in the case of

Fig. 400.
Swamp forest on the Gulf Coast. Bald cypress covered with hanging moss (Tillandsia). In the foreground floating plants, the water hyacinth.

floating leaves the upper surface is in touch with the air. In the latter case there is a great development of stomata in the upper surface of the leaf.

4. *Provision for distribution of food.*—The epidermal cells, as well as the tissues of most water plants, are provided with thin walls where they are in contact with water. This permits osmosis to take place readily between the surrounding water, which contains dilute food solutions, and the protoplasm in the cells. Owing to the loose character of the tissues in the stems and leaves, diffusion from the surface throughout the tissues is not difficult.

5. *Provision for fruiting.*—For most of the aquatic flowering plants it is necessary that the flowers during pollination shall be above the surface of the water. Some curious provisions are made for this, as in the Vallisneria spiralis. The slender, grass-like leaves of this plant are submerged. The stem which bears the pistillate flowers elongates rapidly at time of flowering and lifts the flower to the surface. At the same time the staminate flower-buds, which are borne on short stems at the bottom, break off and float to the surface, where they open and the pollen is scattered. After pollination the flower-scape coils up and draws the flower underneath the water, where the fruit is formed.

6. *Protection from water movement.*—This is provided for in a number of ways, according to the velocity and force of the water, and the habit of the plant. The pliant condition of the stems and leaves gives them considerable mobility in the water, and they are protected from injury which wave motion or currents would inflict on a more rigid habit. Submerged leaves are usually small, or finely dissected. Many of the marine algæ are pliant and tough, so they resist the violent play of the water, or the shock of the breakers against the rock. Postelsia, a marine alga along rocky shores of the Pacific, has a leathery or rubber-like consistency. There is an upright cylindrical stem 2 to 3 feet high, from the top of which hang strap-shaped leaves. These plants with others of similar consistency grow near the edge of the water, where they receive the full force of the breakers as they come in shore. The plants are laid prostrate with each thrust of the wave, and then recover as it recedes. Certain fresh-water algæ, as species of Lemanea, Cladophora, etc., grow in streams where the water plunges over rapids or falls. Certain species grow only where the water is very violent, other species of the same genera where it is less violent, and some species of Cladophora as well grow in quiet water.

953. Mesophytic structures. — Those plants which during the growing season are in general subject to medium or moderate conditions of environment have been called *mesophytes*. In the tropics, where the heat is great but rains abundant and

frequent, the vegetation is mesophytic the year round. In temperate regions, where there is a medium rainfall during the growing season, the land vegetation is mesophytic during this season. But during the winter season, or during the dry season in some regions (part of California, for example), the conditions of environment for mesophytic vegetation are extreme. The extreme cold or dryness during this season would be fatal to plants with mesophytic structures were it not for the fact that the plant is enabled to adapt itself to the periodical change in environment by discarding the mesophytic habit and adopting a xerophytic one. Mesophytes of temperate regions therefore differ from mesophytes of the tropics, and have been termed by Schimper *tropophytes*, because they turn, as it were, periodically from one condition to another.

954. Tropical mesophytes.—Tropical mesophytes in humid districts, being in no danger from extremes of dryness, cold, or excess of salts in the substratum, are free to develop to the highest extent foliage structures, without interruption, for doing a large amount of work in transpiration, respiration, and photosynthesis, which are necessary for rapid growth. We have, therefore, the luxuriance and permanence of foliage in humid tropical regions. The foliage leaf reaches its highest development. To secure the highest efficiency in work we have already learned that the leaf is broad and thin, so that a great amount of surface in proportion to the bulk is exposed to light and air.

955. Temperate-region mesophytes, or tropophytes.—*Growing season.*—During the growing season the general character of the plant structures is similar to that of the humid tropical region. That is, the conditions are such as to favor a high development of foliage. Where the soil is rich and there is an abundance of moisture and an absence of drying winds, vegetation in temperate regions frequently takes on a tropical aspect, even in the northern United States and southern Canada. In drier situations, or in poorer soil, or where dry winds are prevalent, the foliage development is less luxuriant. In fact one finds conditions in all regions so varied that great variations in the

plant population show how sensitive the plant habit and structure are to environment. So in temperate regions there are all gradations from vegetation resembling that of the humid tropics in luxuriance to the vegetation of arid regions.

956. Resting season.—During the winter season, or in some milder climates (California) during the dry summer season, the whole aspect of the mesophytic vegetation is changed. The forests become leafless, except in some for the sprinkling of the evergreen, and xerophytic types found in conifers, heath plants, etc., or where the forest is dominated by these types. The deciduous trees and shrubs having discarded their leaves, which provided them with an immense working surface during the growing season, now enter upon their long rest, with only bulky structures exposed to the air, the surface of which is adapted to greatly resist the loss of water. The twigs, branches, and trunks are protected by their bulk and by the covering of bark, or in some cases the twigs are covered also with hairs. The buds are bulky, and while there are small and delicate leaves and tender growing parts, these are protected from loss of water and consequent death from drying out during freezing weather by the covering of thick dry scales, and in some cases by the additional protection of woolly or hairy scales underneath these.

957. Provision against injury and loss by the fall of the leaf.—Before the fall of the leaf much of the nitrogenous food substances in the leaf slowly passes back into the stem, where it is stored for future use. While this is going on in deciduous trees, the petiole of the leaf near its point of attachment to the stem is preparing to cut loose from the latter by forming what is called a separative layer of tissue. At this point the cells in a ring around the central vascular bundle grow rapidly, so as to unduly strain the central tissue and epidermis, making them brittle. In this condition a light puff of wind breaks them off, and the separative layer of tissue forms a covering which retards loss of water at the wound.

958. Perennial herbaceous tropophytes.—With the approach of winter, perennial herbaceous tropophytes prepare for exces-

sive cold by the maturity and death of their aerial stems and leaves. The underground stems and the roots are thus protected from the great loss of water which would result should the aerial organs retain their power of transpiration. They are further protected by being covered by soil, humus, leaves, etc. In such plants as trillium, Indian-turnip (or jack-in-the-pulpit), blood-root, spring-beauty, Solomon's-seal, etc., the underground stem is a thick rhizome or corm, and contains an abundance of food so that the flowers and leaves formed in late summer or early spring are quickly unfolded and appear as our early flowers. The asters and goldenrods do not have such an amount of food stored in their proportionately smaller underground stems. Their aerial stem and leaves require a longer period of development, and flowers appear from midsummer to late autumn. In some of these plants sometimes the aerial leaves remain green during the winter, but they form rosettes near the ground, and are thus protected from great loss of water.

959. Annuals and biennials.—These, as suggested in paragraph 938, may be considered tropophytes, since annuals every year are carried through the period when the environment is austere by their seed, while biennials are carried through in alternate years by seed and by the rosette type of leaf arrangement close to the ground, and by the short subterranean stem of the first year.

960. Halophytic structures.—*Xerophytic forms.*—The great body of partially submerged vegetation of the salt-marsh and other shallow saline waters is furnished with xerophytic habit and structures. The roots growing in soil saturated with highly concentrated salt solutions absorb water slowly, and consequently the aerial portions of the stems, as well as the leaves, must be able to retard loss of water. This is brought about by modifications of stems and leaves similar to those growing in arid regions. These modifications are reduced leaf surface, accompanied often by a thickening of the leaf, or an increase in mass, in proportion to exposed surface, thickening of the epidermis, thickening of the cuticle, a lessening of the intercellular

spaces, a lesser development of stomata, hairy covering, deeply sunk stomata, slime-cells, water reservoirs, etc. These plants are sometimes called xerophytes, but they differ from most land

Fig. 490a.
Winter condition of forest, the resting season. (Photograph by Rowlee.)

xerophytes in their power to absorb water with a higher concentration of salts without injury to the protoplasm.

CHAPTER XLVIII.

LAWS AND LIMITS OF PLANT MIGRATION.

961. The object of this chapter is to discuss briefly the natural laws of the movement of plants over the earth, not only the movement of plants from one part of the earth to another, into territory beyond its "range," but the movement of plants within territory already occupied by a given species. Manifestly when there are no great climatic or physiographic changes taking place, the laws of movement in general would be the same whether the species was moving into new territory or moving about within territory already occupied by it. The word *distribution* is sometimes employed instead of migration, and it is also used to indicate the "range" or the territory already occupied by a species, or refers in general to the location of the different elements of the earth's floral covering. Migration has also a twofold significance. It may be used to indicate great movements of plants from one region to another during prolonged climatic changes; or movement of species into new territory where conditions are congenial and climate is stable, or back and forth over territory already occupied. The terms are to some extent interchangeable and will not be used here in any strict sense, since the connection in the text will usually make the sense clear. It is not proposed to discuss the geographic distribution of plants in the sense of the "static" distribution. We are not dealing here with the floral elements of the earth, but with the *vegetation* elements.*

* *Flora*, or *floral elements*, refers to *species*. *Vegetation elements* refers to the character of the vegetation without regard to species. Thus several *different species* or *floral elements* may show but *one vegetative type*.

The *distribution* of various vegetative elements is treated in later chapters.

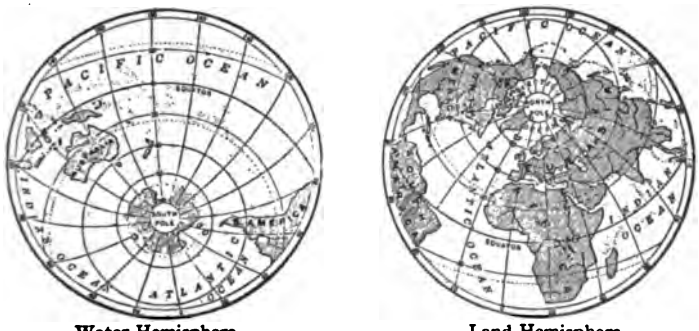
I. Relation of Plants to Earth's Surface as a Whole.

962. Northern hemisphere.—In considering the relation of plants to the earth's surface as a whole, it is at once evident that the northern hemisphere possesses a much larger area for plant distribution than the southern hemisphere. The former comprises the great continents of Europe, Asia, North America, with a number of large islands in the West Indies, with Greenland and numerous smaller islands, and in addition the northern parts of the two southern continents, South America and Africa. The distribution of plant life is mainly on land, and for a limited distance in the waters along the ocean and lake shores. The great part of the oceans and of the larger lakes is not inhabited by plants, chiefly because of the depth of the water where the plants cannot get a foothold, and because of oceanic currents which would in some cases carry floating plants into water of such extremes of temperature that they could not exist. In some of the more quiet oceanic waters, as in the Atlantic, northeast of the West Indies, there are large areas of floating sargassum, known as the Sargasso Sea. Areas on land, devoid of vegetation, are the regions of perpetual ice and snow, as in alpine heights or in the farther arctic regions, or in the extreme deserts. The greater habitable land area of the northern hemisphere, together with the greater extremes of climate and topography, not only assures a larger number of individuals, but also a larger number of species of plants. The plant population is therefore more greatly diversified than in the southern hemisphere.

963. Southern hemisphere.—This includes a fraction of the habitable land area of the globe, the larger part of the continents of South America and Africa, the large island of Australia, the East Indies, and Madagascar, with numerous smaller islands. Besides the smaller land area, the climatic and land variations are not so great as in the northern hemisphere. The actual

land area of the southern hemisphere is probably greater than appears from the map, since it is believed that a great antarctic continent underlies the ice area about the south pole, while it is believed that an ice-covered polar sea lies at the north pole.

964. Land hemisphere, or continental hemisphere.—The northern and southern hemispheres have their centres at the poles. What is called the land, or continental, hemisphere is that half of the globe which contains the largest possible area of



Water Hemisphere. Land Hemisphere.

Fig. 491.

Water hemisphere and land hemisphere showing proximity of continents and islands in the North Polar Zone.

land, and has its centre in western Europe. It includes Europe, Asia, Africa, North America, the northern portion of South America, and the entire arctic region. It is interesting to note this grouping of the continents over one half of the earth, as it shows how near the areas for plant distribution are.

965. The water hemisphere, or oceanic hemisphere.—This includes the southern part of South America, Australia, and the East Indies, with numerous smaller islands. The land area is small and the variations in climate, topography, etc., which encourage variation and increase species are not so great as on the continental hemisphere. The migration of species from one island to another is not so easily accomplished because of the greater distance, though the distance from one land area to another is not more than about one hundred miles at any one point.

966. Opportunities for migration of plants between continents.—Continuity of land areas provides opportunity for migration of plants. Discontinuity of land sets up a barrier to plant migration. Where comparatively large land areas are separated by comparatively narrow bodies of water, their proximity affords greater possibility of the plants passing the barrier, either by floating of plant parts, or seeds, or by seeds being transported by wind or animals. Looking at the map of the northern hemisphere in the region of the arctic circle, it is seen that with north British America, Alaska, Siberia, Russia, Norway and Sweden. the British Isles, Iceland, Greenland, there is a nearly continuous area of land encircling the globe just below the pole. Plant migration from one continent to another here is not so difficult as farther south. Before the glacial periods it was much warmer in the region of the arctic circle, as we learn from the fossil remains of tropical plants found there. In that remote age (tertiary times) it is likely there was communication at this point between plants of the northern continents. But it is very different in the southern hemisphere. The continents of Africa and South America are far separated, and migration of plants between the two continents is well-nigh impossible, and probably has occurred only in exceptional cases. These relations of the continents help to explain why it is that there are so many resemblances between the flora on the continents of Europe, Asia, and North America, while there is little resemblance between the flora on the continents of Africa and South America.

II. Life Regions, Zones, and Areas.

967. Lines of plant migration.—Plant migration takes place along lines of least resistance. Like other questions in plant distribution this one is complex. In general it may be said that the lines of least resistance are those of like temperature areas, and of areas with like moisture content. Plants move more freely over belts the temperature and moisture conditions of which are favorable for their growth and reproduction. Evi-

dently these belts vary for different plants, but there are many plants whose temperature requirements are the same. These come into competition over similar areas. The temperature belts favorable for the growth and reproduction of plants and animals are called "life zones." In general "life zones" are transcontinental, but they do not correspond to belts limited by lines of latitude because of the variations in altitude, and because of warm air-currents from bodies of water which affect areas that do not coincide with latitudinal ones. It was once thought that these life zones coincided with isothermal lines or belts, i.e., those lines or belts formed by connecting numerous points having the same mean annual or seasonal temperature. While this is approximately true in tropical regions where the fluctuations in temperature are slight throughout the year, it does not apply to other regions because of the great fluctuations of temperature, and because isotherms show the mean temperature for arbitrary periods (year or month) which do not correspond with the period of growth and reproduction. The life zones are determined by the *physiological constant* of a species, and may be called biothermal lines, or biotherms.

968. Biothermal lines, or biotherms.—The physiological constant of a species is determined by the total effective heat—that is, the total heat above 6° C., during the season of growth and reproduction. It is the sum of the mean daily temperatures (above 6° C.) during the season from the time when growth begins in the spring (about 6° C. or 43° Fahr.) to the time when growth ceases in the fall (6° C. or 43° Fahr.). By connecting numerous points having the same total heat during the growing season the biothermal lines are known. These lines, which in general are transcontinental, mark the limits beyond which species do not migrate (except in rare instances) in their northward distribution.

969. Life regions.—Three transcontinental life regions are recognized in the northern hemisphere: the Boreal, or Northern; the Austral, or Southern; and the Tropical. These regions were first established by Alexander von Humboldt when he divided the globe into the great life belts. The regions were separated

FIG. 402.

Life zones of the United States, reduced. (After Merriam.)

along isothermal lines, since heat was then recognized as the greatest factor in the distribution of plants and animals. But since the mean temperature of arbitrary periods (annual or monthly) does not coincide with the mean temperature of the season for growth and reproduction, lines were established by Merriam which coincide with the physiological constant of the species. These lines form more accurate limits of the life regions, and may be called *biothermal* lines, or *biotherms*.

The Boreal region covers the whole of the northern part of the continent, from the polar sea southward to near the northern boundary of the United States, and farther south occupies a narrow strip along the Pacific coast and the higher parts of the three great mountain systems, the Sierra Cascade Range, the Rocky Mountains, and the Alleghanies.

The Austral region covers the whole of the United States and Mexico, except the boreal mountain heights and the tropical lowlands.

The Tropical region covers the southern part of the peninsula of Florida, the greater part of Central America, the lowlands of southern Mexico south of the table-land, and a narrow strip on each side of Mexico, which follows the coast northward into the United States.

970. Life zones and areas.—The flora and fauna within each of these great regions are not homogeneous, but present marked differences, which have led to the subdivision of each region into a number of minor belts or areas, characterized by particular associations of animals and plants. Thus the Boreal region is divided into three transcontinental belts or zones, known respectively as the Arctic, Hudsonian, and Canadian; the Austral region, into three transcontinental belts, known as the Transition, Upper Austral, and Lower Austral. The Tropical region is likewise divisible, but the tropical areas within the United States are of small extent. These transcontinental zones are further divided into eastern, central, and western areas, because of the influence and distribution of rainfall. The following table will show the subdivisions:

	Lines of stress due to heat.	Lines of stress due to rainfall or drought.
Boreal Region.....	Arctic or Arctic-Alpine Zone.	
	Hudsonian Zone.	
	Canadian Zone.	
Austral Region.....	Transition Zone.....	Alleghanian Area.
		Arid Transition Area.
		Pacific Coast Transition Area.
	Upper Austral Zone.....	Carolinian Area.
		Upper Sonoran Area.
	Lower Austral Zone.....	Austroriparian Area.
		Lower Sonoran Area.
Tropical Region.....		Humid Tropical
		Arid Tropical.

971. The great lines of stress.—There are here shown two great systems of parallel lines of stress which influence and limit plant migration. One of these systems of stress is traceable to the factor *heat*, and the stress lines are in general transcontinental (east and west). In the eastern and western portions of the continent, however, these temperature stress lines are deflected far to the south because of the mountain ranges and become parallel with continental lines. So mountain ranges constitute lines of stress, but the great factor influencing plants is heat, since plants in attempting to cross mountain chains meet with the extreme cold of mountain-tops. The other system of stress lines is due to difference in rainfall; the interior of the continent having a slight amount of rainfall as compared with the abundant rainfall nearer the coast and along the mountain ranges (except in the southwest), these lines run across the temperature stress lines. Large bodies of water also constitute lines of stress.

972. Lesser lines of stress.—Lesser lines of stress are formed by streams and small bodies of water, as well as by the lesser physiographic variations of the earth's surface. For example, between ponds, marshes, swamps, etc., and the surrounding higher elevations; between rocky areas, sandy areas, and soil

rich in humus; between alkaline areas and those with a small salt content, and so on. A study of the vegetation elements along these lesser lines of stress is possible in any locality where one may see the struggle along the border line between plants occupying different kinds of territory.

973. Total heat as limiting factor in north and south migration.—According to Merriam plants and animals are limited in their northward distribution by the sum total of heat (above 6° C.) during the period of growth and reproduction (the sum of the effective temperatures), but they are limited in their southward distribution by the mean temperature of the hottest part of the year. Since some plants and animals require a larger sum total of heat than others, they are drawn into these different life zones in accordance with their temperature requirements. But singularly on the Pacific slope there is greater mixing of boreal and austral forms, the boreal forms extending far southward and the austral forms far northward. This is due to the more equable temperature during the reproductive period. The comparatively low mean temperature during the summer permits northern forms to go far southward; while the high sum total of effective heat permits southern forms to go far northward (see characters of the Pacific coast transition area, Chapter LVII).

974. Limiting factor for east and west distribution in United States.—On the other hand, plants and animals are limited in their east and west distribution in the austral and tropical regions of North America by difference in rainfall and humidity, the great arid area in the centre of the continent affording an effectual barrier to the west or east movement of the east or west forms, while the forms of the arid area are prevented from moving east or west of this area partly by the dominance of the forms in the humid area and partly by the specialized character of arid area plants unfitting them for humid climates. The mountain ranges also to some extent limit east to west distribution, but the factor here is heat, and these areas as pointed out above are southward extensions of the general transcontinental zones.

These zones and areas established by Merriam, and the laws governing them, have not yet been subjected to a sufficiently thorough test so far as plants are concerned, and there are many cases of plant distribution which they do not adequately explain. Nevertheless they are in general accord with several great factors of plant distribution and are worthy of careful study and test. Modifications it may be necessary to make, though in general the fundamental principles seem well grounded. The limits of these life zones and areas in the United States can be seen by consulting Fig. 492. The limits and the characteristics of the life zones and areas of North America are given in Chapter LVII.

III. Methods and Causes of Plant Migration.

975. Advantages of plant migration.—The advantages accruing to plants through their power or tendency to migrate is that individuals of a species are increased by extending their area of occupation. Whether the plant concerned occupies any given area to the exclusion of other species or not, an extension of the area provides for an increase in individuals, and the perpetuation of species is thus more surely safeguarded. It increases the factor of safety for existence: 1st. By the larger number of individuals possible over a larger area. 2d. The safety of some is assured in case of disaster to others in a certain region. Disaster may come by sharp competition of other species, or by the destructive effect of physical changes in the topography of certain areas. For example, in time of flood, areas being covered by sand, gravel, or other rock débris; or by changes in the climate, etc. 3d. The species often gains in vigor by coming under new conditions, better soil conditions, more favorable climatic conditions, etc.

976. Structural characters favoring plant migration.—Many of these characters are discussed more fully in the chapter on "Seed Dispersal," and others in the chapter on "Stems," etc. The mere enumeration of some of these characters is given here.

1. *Seeds.*—1st. The buoyancy of seeds produced by the development of so-called "wings" on the elm, maple, etc., the pappus of the composites, and other hairy or woolly outgrowths, form part of the seed or fruit which enable it to catch the wind. Small size and lightness of many seeds also give them a certain amount of buoyancy. 2d. The development of structures for grasping hold upon other objects; for example, barbs and hooks on seeds or fruits for clinging to animals. 3d. The use of seeds as food by animals. 4th. Seeds which are capable of floating on the water.

2. *Fruit.*—There are many fruits which are used for food by animals and the seeds of which often pass through the body uninjured, and thus often gain wide distribution. Exploding fruits also bring about the dispersal of seed, as in the vetches, the touch-me-not, the fruit of the witch-hazel, or of spores, as in the sporangia of ferns, or of some of the fungi.

3. *Tumble-weeds.*—Several kinds of tumble-weeds are known, some of which are popularly spoken of as "resurrection-plants," especially certain species of club-mosses (Lycopodium). These, as is well known, in dry weather curl their stems into a more or less round, compact ball, and in so doing the roots are frequently torn from their attachment to the soil, and the ball is rolled along by the wind over plains to considerable distances. During the rainy season these plants, which have retained their life in the dry condition, expand and the roots take hold of the soil again. Parts of plants, as the seed-bearing portion of certain grasses, are often broken during heavy winds, and are blown or rolled for a considerable distance over the ground, thus providing for the distribution of seed.

4. *Floating of broken branches.*—In the case of certain trees or shrubs growing next to water the branches are often broken by the wind and, floating to new places, sometimes aid in the distribution of the species.

5. *Prostrate creeping plants* or plants with a more rampant habit migrate through a system of natural layering. In prostrate or creeping plants, like the strawberry, or trailing roses, the

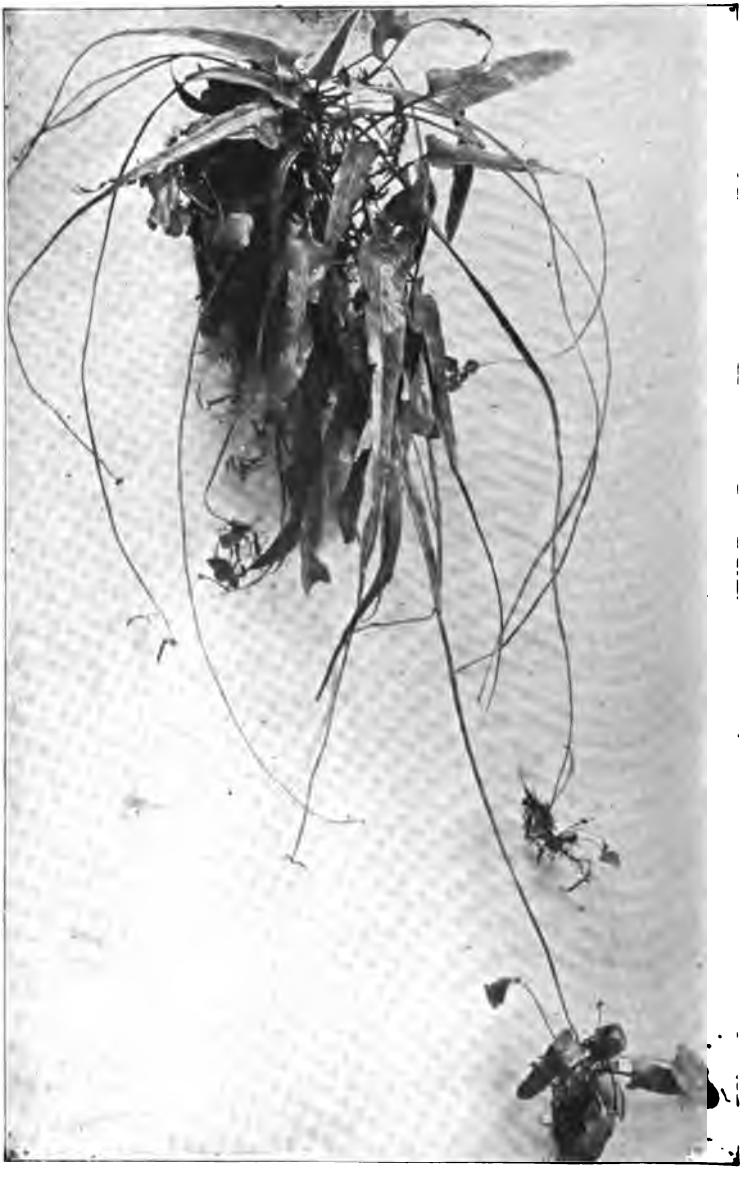


Fig. 403.
Walking-fern, climbing down a hillside.

stems take root here and there, and thus slowly but surely extend the area of occupation by the species. Plants of more rampant habit, like the blackberries, or certain other roses, take root at the tips of their branches, where they come in contact with the ground, and new shoots develop at this point. This habit is sometimes spoken of as the "walking" habit, and is well illustrated by the "walking-fern" (Fig. 493).

6. *Underground creeping stems or roots.*—Of this type there are a large number of well-known examples, the underground shoots of many grasses for example, of ferns like the sensitive fern, or bracken-fern. Among those which extend their distribution through roots, a striking example is that of certain species of sumac. In New York State several species of sumac by their seeds gain foothold in abandoned fields or in pastures. The roots of these species spread many feet just underneath the surface of the soil, and each year from these roots new shoots are developed. The sumac often spreads from 5 to 10 feet per year in this way.

977. Causes of plant migration.—In general the causes of plant migration may be grouped under two kinds of factors: 1st. What may be known as biotic factors. 2d. Physical and climatic factors.

1. *Biotic factors.*—These factors are found both in the agency of animals and plants themselves. Animals bring about plant migration through the eating of fruits and seeds, or by dispersal of seeds which cling to their bodies. Causes of plant migration initiated by plants themselves are found in: 1st. Fertility of species by which seed results. Plants which have the power to develop large numbers of fertile seeds with the best means for seed distribution not only gain distribution through the seed, but by the crowding of certain areas bring about pressures. 2d. The centrifugal habit of self-propagation by runners, by layerings, or by the propagation of stems from separate roots. 3d. The factor of adaptation to environment, or acclimatization.

2. *Physical and climatic factors.*—Some of these have already been mentioned under the head of structural characters favor-

ing plant migration. 1st. There are certain physical factors, as wind, water, which float seeds of various plants to great distances. Then the increase of depth of water or the lowering of depth of bodies of water forces to a limited extent migration of plants along other shores. 2d. Tensions in fruits; for example, exploding fruits. 3d. Climatic pressures. These pressures are brought about from variations in the climate, those variations which extend over long periods of time. The most noted of these pressures upon plant distribution occurred in what is known as glacial times. During this epoch of the earth's history a great ice-sheet formed in Canada and British America, flowed down across the border and over a great portion of the northern United States. This great change in the climate, the intense cold for so many ages gradually extending southward, forced the plants of northern North America southward. Those which were not able to migrate in advance of the glacier perished.

978. Action of glaciers.—Geologists have learned from a study of the formation and movement of mountain glaciers and of the great ice-sheets covering Greenland and other arctic lands how to determine the former presence of similar glaciers by marks which they have left upon the surface of the land. These great masses of ice, possessing enormous weight, grind upon the rock surface, ploughing out basins and scouring the rocks over which they pass. The great scouring action is produced by rocks which become fastened in the lower surface of the glacier, and so shoved along by its movement, ploughing and gouging into the solid rock below. Along the advancing edge of the glacier or ice-sheet, where it is melting, these rocks, gravels, and clays, mixed together, are deposited, forming what are known as the terminal moraines.

979. Limits of the great glaciers.—According to geologists, the great ice-sheet which flowed down over the northern United States was gathered on the uplands of Canada and British America by a great and long-continued fall of snow. The pressure of great bodies of snow formed with the ice-sheet, and this, by its own weight, was forced to flow to the southward where there was less snow on account of the warmer temperature. The ice-sheet in its southern movement extended down to the "southern border of New England, across New Jersey, Pennsylvania, and southwestern New York, and then followed a crooked course north of the Ohio River. It nearly followed the Missouri River across Missouri, and then northwest through Nebraska and the Dakotas and Montana. Much of

our western mountain region where a few remnant glaciers are found was covered with ice, continuing into the great ice-fields of British Columbia." The ice flowed over the north Alleghany Mountains, over the Adirondacks in New York, smoothing and rounding them. All along the southern line of the glacier are the waste materials, forming terminal moraines, which have been carefully studied by geologists. Evidence goes to show that after the first onward movement of the ice-sheet a warmer period came, and the ice-sheet retreated northward, and many ages afterward extended again to the south, nearly to its former limit. Since this last glacial period the ice has receded until the glaciers now occupy only the higher mountains in the northern Rockies, and Alaska and Greenland.

During the same period a similar ice-sheet covered all northern Europe, extending as far south as the Thames Valley in the British Islands; the North and Baltic Sea basins, northern Germany, and northern Russia were occupied.

980. Effect of the cold wave on plant migration.—The presence and movement of these great sheets of ice southward over the northern hemisphere forced the migration of northern species southward. As the ice-sheet reached into the temperate regions it forced in advance of it the species from the temperate regions southward. As the glacier retreated northward, the plants which were able to survive by southward migration again migrated northward. Geological evidence goes to show that there were a number of movements back and forth of the ice-sheet. This great climatic pressure, therefore, fluctuated for long periods, forcing the plants southward, then again yielding and allowing the plants to take up their former positions, when again they would be forced southward, and so on.

981. Evidences of plant migration in glacial times.—In studies of the distribution of the plants of North America and Europe and Asia, there are at present evidences of this migration of plants southward. Many arctic plants which at that time moved southward are now left on the higher mountain peaks, or in the cool sphagnum moors formed among some of the terminal moraines. With the proximity of the continents in the arctic circle there is reason to believe that in former times plants migrated readily between the continents of North America, Europe, and Asia. During glacial times these were forced southward,

both in Europe, North America, and Japan. Evidence of this is shown in the close relationship of the flora of northern Europe, North America, and Japan. Many species and genera of plants are found in these countries which are the same. Under the present conditions of the climatology of the earth, it would be impossible for the plants to communicate to such an extent as to explain the presence in these different continents of such a large number of the same species. While in the seed plants there are many similarities in the flora, and many species and genera are identical; in the lower forms, among the algæ, fungi, liverworts, and mosses, there is an even greater similarity. This leads us to believe that even microscopic plants like the fungi and algæ migrated under these conditions along with the seed plants. The parasitic fungi moved along with their hosts, and saprophytic fungi, like the mushrooms, followed the movements of forest trees, growing on dying or dead trunks, upon the leaves, and leaf-mold in the forest. The aquatic fungi and the fresh-water algæ likewise moved southward with the aquatic flowering plants. The fact that so many of the fresh-water forms of the fungi and algæ are identical with many of those in northern Europe suggests that in former times the continents in the arctic circle were very near together, if not actually connected, that the climate was milder, and that there was a migration of these fresh-water plants between the continents This might be brought about by a possible continuity of land and fresh-water areas, or through the migration of water-fowl tne spores of algæ and fungi clinging to their feet could be transported across land areas or channels of salt water, when these were not too wide, and lodged in the fresh-water pools, or lakes, or streams of another near-by continent.

982. Present climatic pressures.—Other climatic pressures also existed and continue to the present time. In the humid tropics large numbers of individuals of different species were propagated, which produced a pressure northward and southward from this point, but those moving southward on the northern hemisphere come in contact with those moving northward,

and here a lateral pressure is exerted which crowds the plants to the west and east. Pressures also exist in the borders of arid regions. The fertility of aggressive species wherever they occur tends to produce pressures in all directions.

983. Barriers to plant migration.—There are a number of barriers which plants meet in their migration over the surface of the earth. In general terms we might speak of four when looking at the world as a whole. 1st. *Kinds of climate:* regions of great heat or cold, of dryness or moisture, etc. All these regions oppose obstacles to the entrance and passage of plants which are accustomed to live in different climates. 2d. *Kinds of soil;* for example, the alkaline deserts and the great salt steppes present effectual barriers to the passage of plants not provided with adaptations which would enable them to live under such extreme conditions 3d. *Discontinuity of land.* Here bodies of water present a barrier to the passage of plants from one continent to another, or from one island to another, which are separated by broad lakes or seas. A good illustration of this is shown in the relation of the continents of the southern hemisphere as compared with those of the northern hemisphere already pointed out. 4th. *Mountain chains.* High mountain chains, because of the great cold, often form impassable barriers for plants; good illustrations of this are shown in a comparison of the number of species of plants in Europe and North America and their distribution. Under the high climatic pressures which existed, for example, in glacial times, the plants of North America met with no barrier in their southward movement; probably a large percentage of them survived. In North America the mountain chains were parallel with the migratory movement and permitted the southward flow and return of the species. On the contrary on the continent of Europe dur'ng the same period in their southward movement the plants met with an impassable barrier in the Alps and Pyrenees Mountains, which extend east and west across southern Europe. Many of the species thus perished and were not left to join in the return movement in populating the continent after the disappearance of

the ice-sheet. Likewise the Alps and Pyrenees presented a barrier to the northern movement of the plants of southern Europe. The Rocky Mountains afford a barrier between the flora of the Pacific coast and the country to the east.

983a. Conflict of species in migration.—This is one of the most noticeable features in plant migration. With the means for movement with which plants are provided, together with the pressures exerted, forcing them to move, they are constantly reaching out for new territory and struggling to hold that which they already occupy. The competition becomes severe because of the large number of species which are adapted to live under similar conditions. Some have compared the struggles of plants to occupy new territory, or to maintain their hold upon their own, to the competition which exists among human societies. Every plant must be able to propagate itself and to hold territory in competition not only with climatic conditions, but also with other plants entering the same region. It must either hold its territory or cede it to its more successful rivals. Thus plants which are best adapted to live under the conditions of a given territory are those which survive, while the weaker ones are driven out, or exterminated, or occupy a very subordinate place in the society.

CHAPTER XLIX.

PLANT FORMATIONS.

984. The general formations.—Wherever the conditions of environment are such as to develop one or another vegetation type in such abundance that it becomes the dominating vegetation type of the region or area it is known as a *formation.* A single plant or a few plants may represent a vegetation type, but do not constitute a formation. The massing together of a vegetation type, though it may be represented by many widely different species, so that the area is characterized by this type as the dominant one, constitutes a formation. There may be other types mixed which either appear at certain favorable seasons (example, the rainy-season flora in the desert formations) or represent a few subordinate individuals. The total combined dominant vegetation of any one type constitutes a general formation. The general formations may be grouped first in four divisions.

1. Climatic Formations.
2. Edaphic Formations.
3. Aquatic Formations.
4. Culture Formations.

I. Climatic Formations.

985. The plant covering of the earth is not uniform.—This is due in a great measure to the lack of uniformity in climate, topography, and soil. Climatic influences extend over wid-

regions. They do not govern special types of plant communities. Climate controls the general type of vegetation of a region. In the sense of control there are two climatic factors, temperature and moisture, especially soil moisture. Temperature exerts a controlling influence only over the general vegetation type where the total heat during the period of growth and reproduction is very low. This occurs in polar lands, so that the arctic zone (including alpine areas on high mountains) has a distinct general vegetation type which is controlled by temperature. This is the arctic vegetation of the *Cold Wastes*, or *Tundra*, the land where the ground in many places is perpetually frozen and only thaws out on the surface during the short summer period. In the temperate and tropical regions of the globe, moisture, *not* heat, is the controlling factor in determining the general vegetation types. These are in general coincident with rainfall distribution, and there are here, according to Schimper, three great vegetation types controlled by climate: the woodland, the grassland, and the desert. There are, then, according to Schimper, four climatic formations, as follows:

986. (1.) **The Arctic-Alpine Formation.**—The determining climatic cause is temperature, as indicated above.

987. (2.) **The Woodland Formation.**—This is characterized by woody plants, whether trees or shrubs. If a close formation of trees, it is a *forest;* if clumps of shrubs separate the trees so the crowns do not meet, it is a "*bush*"; or if the shrubs dominate, it is a *thicket.* The woodland formation is a close formation, i.e., the climatic conditions are such that freedom of growth is permitted over the entire area. The plants are not struggling against climate, but compete with each other, and the entire ground being occupied the formation is *close.* If there are bare places here and there, or places occupied by herbage, they are mere accidents, due to factors acting temporarily, or to differences of soil (i.e., ground). There also may be spots which are xerophytic or spots which are hydrophytic, but these are due to soil, not climatic factors. The unfavorable condition of the soil here overcomes for the time the climatic influence.

The entire region is a *potential woodland formation*, i.e., if left to the operation of natural forces, in time a forest would develop over the entire area unless interrupted by great climatic or physiographic changes. It is the region of normal to excessive rainfall, and in North America covers practically the Hudsonian and Canadian zones and the Alleghanian, Carolinian, Austroriparian, and Pacific Coast transition areas, the Austral region and wooded slopes of the Rocky Mountains, as well as the humid tropical area.

988. (3.) **The Grassland Formation.**—This is also a close formation, since the climatic factor, humidity, is still favorable to the abundant growth of a vegetation type. Here the vegetation consists of tufted and perennial grasses as the dominant and potential element, although other herbage may exist here and there as an accidental or subordinante element. This is the region of less rainfall and high winds, a transition region between the woods type and the desert. In the evolution of the woods and prairie types they have come into sharp competition for the occupation of the debatable border territory with wide invasions of each type into the interior territory of the other, like the armies of two nations struggling for the occupancy of territory where the border line is as yet ill-defined. Climatic conditions finally turn the balance in favor of the woods or prairie, according as the degree of humidity of the region aids one above the other, and the border line becomes established. This is not sharply defined unless there is some natural physical barrier, as a chain of mountains, while on the plain or level the transition line shows a commingling of the two types.

989. (4.) **The Desert Formation.**—Here the moisture of the soil as well as the humidity of the atmosphere is very low and the conditions of life become so austere that plants cease their conflict with neighbors for territory because the conflict with climate is so great as to keep down the numbers and leave unoccupied spaces. Here the two general vegetation types (woodland and grassland) mingle because there is plenty of room for all that can survive. Millions of seeds are scattered which

never germinate, or if they do, dry up before they even get a temporary foothold. In the woods and prairie types millions of seeds germinate and gain temporary hold, only to be crowded out later by competition among themselves. In passing from the prairie to the desert there is a large transition area, the ***plains*** where the formation is open. It is neither prairie nor desert

Fig. 404.
Desert range near Mirage, Nevada. Open formation, almost pure salt bush (Atriplex confertifolia). (After Griffiths, Bull. 38, Bureau Plant Ind., U. S. Dept. Agr.)

but is intermediate. It might be treated of as a fifth formation, the Plains Formation.

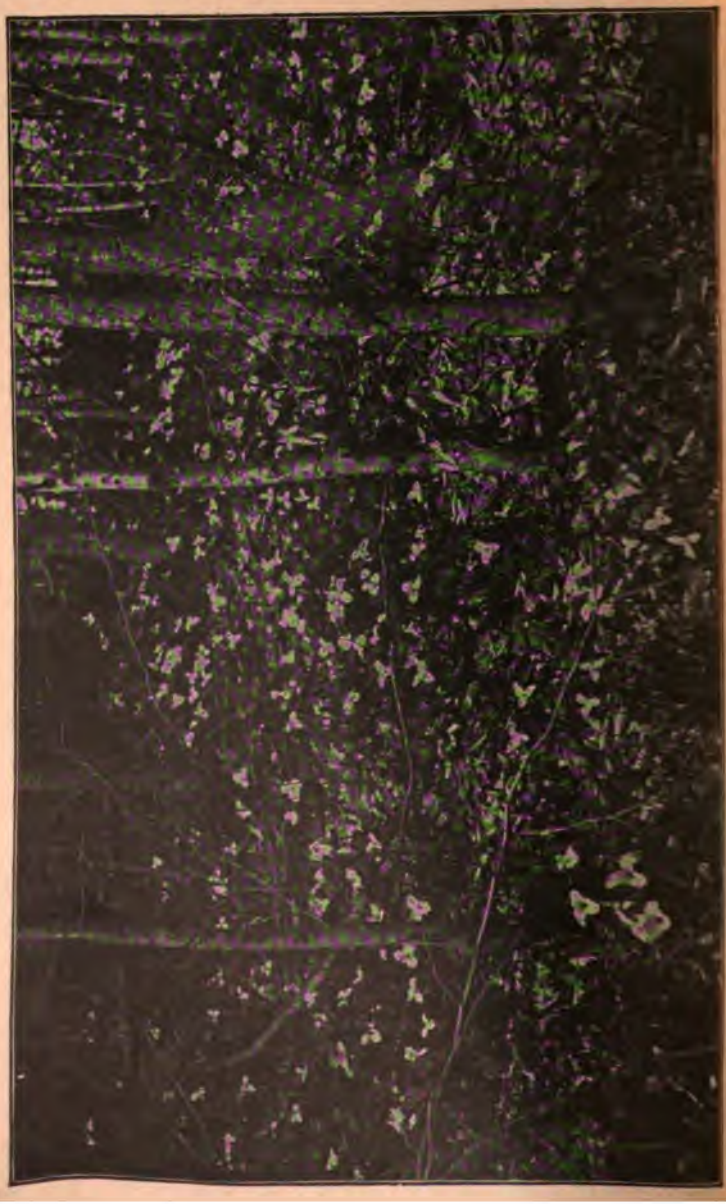
II. Edaphic Formations.

900. Controlling factors.—Climatic formations do not cover the entire surface of the earth over which they extend, since soil (ground) conditions present limiting factors which in many places overcome the general climatic influence. The influence of different kinds of soil gives a more checkered appearance to the vegetation because within climatic regions there is great diversity of soil and soil conditions. Limited areas are thus mapped into small or large natural parcels. Those of like conditions, even in the same climatic region, are separated from each other by the intermediate spots of a different soil condition.

Each one of these limited areas or spots of soil furnishes a characteristic ecological or vegetation type of plant community. The climatic formations are thus infiltrated, as it were, with plant communities determined by soil conditions, in some places filling in cavities or interspaces, and in other cases actually intermingling with the elements of the climatic types. These plant communities are termed by Schimper *edaphic formations*. Thus rocky places or shores, sandy areas or dunes, certain swamps or moors, etc., represent interspaces in the woods type which are occupied by edaphic, or soil, plant formations.

In prairie regions where the ground is rolling, subordinate herbs may give the formation a variegated appearance, i.e., when Primula officinalis occupies the dry places and P. elatior with differently colored flowers occupies the damp places. At Simplon in dry alpine meadows, Senecio unifloris with large flowers occurs on thin soil covering rocks, Senecio incanus occupies deeper soil, but never were they mixed. The hybrid form occupied soil of an intermediate depth (Schimper). In culture meadows or pastures where the surface of the ground is undulating the field is often covered with patches of yellow and white flowers. In the low ground there is a rich infiltration of buttercups (Ranunculus acris), and on the higher ground of ox-eye daisies (Chrysanthemum leucanthemum). So in the forest region conditions of the ground may be such as to modify the appearance of the forest, encouraging certain kinds of trees in one locality, others in another. The modifying influence, however, is not sufficient in these cases to change the vegetation type. It still retains the climatic character.

991. Open edaphic formations.—These are controlled by physical or mechanical conditions of the soil of such a nature that the struggle for existence is with the adverse conditions of the ground and not with rival plants. The result is the same as in the desert, where the struggle is with climate, not with soil, and there may be a mixture of the elements of the woods or prairie regions. There are three marked types of open edaphic plant societies: 1st, the vegetation of rocky places; 2d, the



vegetation of the sandy beach or strand; 3d, the vegetation of the "bad lands" and alkali marshes.

992. Close edaphic formations.—While these are controlled by conditions of the ground, these conditions are not so austere as to prevent the development of a close growth. In the forest region too much water in the soil may prevent forest growth, but encourages a rank growth of marsh plants. Some of the examples of close edaphic formations are: 1st, mud or reed-swamp formations; 2d, meadow-swamp formations; 3d, sphagnum moor formations. The "park-like forests" along river bottoms in the prairie region or the "oases" in deserts are close edaphic formations in these regions, since they are not developed in response to the climate, but in response to a condition of the ground (the abundance of ground water), although the type of the vegetation is really that of the forest.

III. Aquatic Formations.

993. These are represented by the vegetation in ponds, lakes, streams, and in the ocean. The vegetation is of a type very distinct from the climatic or edaphic. The formations occur as patches or strips infiltrated in the climatic and edaphic formations, and also as a fringe along continents, islands, or bodies of land bordering deep and large bodies of water. The character of the vegetation is hydrophytic or halophytic, according to its occurrence in fresh water or salt water. There are, therefore, two grand subdivisions: 1st, fresh water or limnetic formations; 2d, salt water or pelagic formations.

IV. Culture Formations.

994. This type of vegetation is developed in response to the work of man in the cultivation of the soil, or as a result of his interference with the development of the climatic type of vegetation. Man overcomes the climatic factor by removal of the climatic vegetation type and by the cultivation of the soil; in

arid regions by irrigation in addition to cultivation. In a broad sense there are two general types of the culture formations: 1st, the vegetation of cultivated fields; 2d, the vegetation of waste places. There is not space in this book even for a satisfactory outline, and no discussion of these formations will be given. Only a few of the prominent culture formations will be mentioned at this place.

995. Vegetation of cultivated fields.—Here belong the field and garden crops. Examples: the cereals (wheat, etc.), corn, rice, potatoes, meadow grasses, pastures, cotton, cane, beans, beets, orchard fruits, berries, vegetables, gardens of various kinds, and forests in some cases.

995a. Vegetation of waste places.—This would include ground once cultivated or cleaned and later abandoned for the time or devoted to other purposes. Examples: the vegetation of roadsides and road embankments, of abandoned fields, of yards or areas not devoted for the time to agricultural or horticultural purposes. The plants growing in such places are usually called "weeds," though "weeds" are often very abundant in culture formations and sometimes develop to such an extent as to entirely overcome them.

V. Principal and Individual Formations.

996. The principal formations.—The term formation, or principal formation, is used by some in speaking of the dominant vegetation of places more or less limited by distinct physiographic areas. In this sense the formation, or principal formation, is not very different, if at all, from a single edaphic formation, or single water formation. It is made up of the different individual formations which are the dominant vegetation forms in the zones or plats which are usually present on different portions of the same physiographic area.

997. Plant societies.—The term plant society is used by some in a broad sense to include all those plants living together over an area possessing a nearly or quite uniform *ground* con-

dition and environment. *Ground* is here used in a broad sense to mean the earth substratum in or upon which the plants grow, and includes water areas as well as land areas. In this sense different plant societies occupy somewhat distinct physiographic areas, as marsh, moor (or bog), strand, rocky areas, sandy areas, ponds, lakes, etc. These areas may be quite limited in size, or they may cover many thousands of square miles. The territory of a plant society, then, is in many cases coincident with the territory of a single area of the edaphic formation, or equivalent to the area of a principal formation. But the term *society* is generally used in a broader sense than formation, which refers more to the dominant vegetation.

998. The individual formation.—In each plant society, while the general aspect of the vegetation is the same, there are certain limiting factors which give it a more or less variegated appearance. These factors are of two kinds: 1st, the *physical*, which relate to the variation in ground water, and to physical and chemical conditions of the soil; and 2d, *biological*, which relate to the struggle between different species to occupy the same patch of ground. Distinct groups of vegetative elements are thus formed in a society because in certain more or less limited areas one or several species are dominant and give a characteristic physiognomy to the area. Such a group in a society is called a formation.* In reality the different formations resemble pieces of mosaic, when arranged without order, or zones when arranged regularly where there is radial or lateral topographic symmetry. This is well illustrated in certain marshes, or in shallow water, along margins of lakes, where there are

* Formation is used in this sense by some, while others use here the term *association*, reserving the term *formation* for a group of associations, i.e., a *principal formation*. But the term association itself does not seem well chosen. The word seems more applicable to certain "associations" in a society or formation, i.e., certain of the subordinate members (example, lianas, epiphytes, or other subordinate members). Some even propose the word society for epiphytes and lianas, and cite Schimper's use of it in this connection. Schimper uses for epiphytes the term Genossenschaft, which means rather an *association* or *guild*.

often extensive patches * or areas of the cat-tail flag, which appears at a little distance to occupy the area to the exclusion of all other vegetation. In similar locations are patches of arrow-leaf, of rushes, reed grasses, etc. In low damp ground near bodies of water or streams, the alders and willows often form each a distinct patch or zone. In forests there are often distinct groups of white pine or of pitch pine, sometimes of maple or beech. Smaller plants are often between the larger ones composing these groups, or in their shade, but the larger plants so closely associated are dominant and characterize the area.

The various groups above described would then be called cat-tail–flag formation (or Typha formation), arrow-leaf formation (Sagittaria formation), Cassandra formation, white-pine formation, etc. (The same formations are sometimes called also *typhetum*, *sagittarietum*, *cassandretum*, *pinetum*, etc.) In the cases just cited above, a single species is dominant, and it is a pure formation. In many cases the individuals of several species may share the same spot or area of ground equally or nearly so. In the former case the individuals of the one species are able, in their competition with others, to occupy the ground to the exclusion of their competitors, either because they possess characters which enable them to gain the upper hand, or because competing species may not have been present at the start. When the individuals of several species occupy equally the same ground, the formation is mixed. The conditions are favorable for the growth of several dominant species, and all, as it were, feed at the same table, with no greater competition between the individuals of several species than there would be between the individuals of one species were only one species present. This mixture of several species of the same grade of dominance is sometimes called *commensalism*, and the term is also extended to mixtures where individuals of smaller species are mixed in between those of larger ones or in their shade, and do not come into actual competition with them. Examples

* All small patches should not be regarded as a formation.

of mixed formations are seen in the mixture of joepye-weed and boneset in low ground. This would then be a joepye-weed-boneset formation. Each of these, however, often grows separately, and then would form pure formations. In the forest, beech, birch, and maple are sometimes mixed, forming a beech-birch-maple formation. Again, oaks, beech, maple, and hemlock may form an oak-beech-maple-hemlock formation, and so on, which may vary in different patches of an area, even where the general conditions are the same, and the name of the formation would vary accordingly. Besides the dominant species of a formation there are subordinate species which may not be prominent enough to change its aspect, but at most only modify it.

999. Facies.—The term *facies* is sometimes applied to each of the dominant species in a formation. Where there is but one dominant species there is a single facies; where there are several dominant species in a formation each one is a facies.

1000. Vegetation forms.—Vegetation form refers to the special ecological form which individual species of a formation take under the conditions, without regard to the importance of the species in the formation. One or several vegetation forms may be dominant (these would constitute the facies of the formation), while others are subordinate or even inconspicuous.

1001. Layers.—By layers is meant the different strata in a formation or society. While these are present to some extent in nearly all plant societies, they are more marked in the forest societies. The forest trees because of their greater height form a canopy which shades the interior. The tall trees constitute, therefore, the upper layer. Large shrubs growing in the forest would constitute a second layer, small shrubs a third layer, herbaceous plants a fourth, mosses, lichens, etc., on the ground a fifth, and so on. The layers may in some cases be even more numerous.

1002. Zones.—Applied to vegetation this refers to *lateral* layers so clearly shown where there is radial or lateral topographic symmetry.

1003. Summary of formations.

GENERAL FORMATIONS.

- I. Climatic (controlled by climatic factors).
  - 1. The woods or forest formation.
  - 2. The prairie formation.
  - 3. The plains formation.
  - 4. The desert formation.
  - 5. The arctic-alpine formations.
- II. Edaphic (controlled by ground factors).
  - 6. Edaphic or soil plant formations.
    - *a*. Rocky places.
    - *b*. Sand areas.
    - *c*. Marshes, moors, meadows.
    - *d*. Alkaline areas, etc.
- III. Aquatic (controlled by bodies of water).
  - 7. The aquatic formations.
    - *a*. Fresh-water formations.
    - *b*. Salt-water formations.
- IV. Culture (controlled by man).
  - 8. The culture formations.
    - *a*. Cultivated areas.
    - *b*. Waste places.

PRINCIPAL FORMATION (*society*) (controlled chiefly by distinct physiographic areas).

1. Layered.
2. Zoned.
3. Built up of vegetation forms.

Individual Formations (controlled by physical and biological factors).

1. Layered.
2. Zoned.

(One or several facies make up the formation).

1004. The terminology of plant communities is at present in a very unsettled state, and it is necessary for nearly every writer to define the terms and the limits of their application. Without

attempting to decide what system of terminology should be used, the author feels it is best in this treatise for elementary use to employ the terminology given above. The discussions here will center on the society, since it is believed that it will be more useful in this elementary work to treat the subject rather from the broad standpoint of the plant society, showing the interrelation of members of different grades and the general relation of dominant members to environment. The various systems used by different writers can be found in their works listed at the close of this part.

1005. Complex character of plant societies.—In their broadest analysis all plant societies are complex. Every plant society has one or several dominant species, the individuals of which, because of their number and size, give it its peculiar character. The society may be so nearly pure that it appears to consist of the individuals of a single species. But even in those cases there are small and inconspicuous plants of other species which occupy spaces between the dominant one. Usually there are several or more kinds in the same society. The larger individuals come into competition for first place in regard to ground and light, the smaller ones come into competition for the intervening spaces for shade, and so on down in the scale of size and shade tolerance. Then climbing plants (lianas), and epiphytes (lichens, algæ, mosses, ferns, tree orchids, etc.), gain access to light and support by growing on other larger and stouter members of the society. (See evergreen tropical forests, Chapter L.)

Parasites (dodder, mistletoes, rusts, smuts, mildews, bacteria, etc.) are present, either actually or potentially, in all societies, and in their methods of obtaining food sap the life and health of their hosts. Then come the scavenger members, whose work it is to clean house, as it were, the great army of saprophytic fungi (molds, mushrooms, etc.), and bacteria ready to lay hold on dead and dying leaves, branches, trunks, roots, etc., disintegrate them, and reduce them to humus where other fungi change them into a form in which the larger members of the plant society can utilize them as plant food and thus continue the cycle of matter through

life, death, decay, and into life again. Mycorhiza (see Chapter IX) or other forms of mutualistic symbiosis occur which make atmospheric nitrogen available for food, or shorten the path from humus to available food, or the humus plants feed on the humus directly. Nor should we leave out of account the myriads of nitrate and nitrite bacteria (see Chapter IX) which make certain substances in the soil available to the higher members of the society. Most plant societies are also benefited or profoundly influenced in other ways by animals, as the flower-visiting insects, birds which feed on injurious insects, the worms which mellow up the soil and cover dead organic matter so that it may more thoroughly decay. In short, every plant society is a great cosmos like the Universe itself of which it is a part, where multitudinous forms, processes, influences, evolutions, degenerations, and regenerations are at work.

CHAPTER L.

FOREST SOCIETIES.

I. General Character of Forest Societies.

1006. Extent of forest societies.—Forests represent the highest stage of evolution in plant communities. Some forests represent also the most complex stage. In their distribution forests range from the tropics to subarctic regions, from wet and marshy lowlands to high mountain altitudes, and they are also transcontinental. Their farthest north is limited by arctic cold, their highest altitude by alpine cold and winds, their breadth of distribution by bodies of water, by wind, and by desert conditions. The forest is the climax type in the evolution of plant communities, and the only hindrance to complete occupation of the land are exteme cold, dryness, frequent and severe winds and fire, and the needs of human civilization.

1007. Complexity of forest societies.—All plant communities are more or less complex, but the forest type is the most complex of all. This is due to the fact that in the forest there is the greatest divergence among its members in point of style, form, character and work. The abundance of the tree type stamps the community as a forest. Trees are the largest plants. The bacteria, abundant in all aerated soils and in decaying vegetation, represent the smallest individuals. Between these two extremes there are gradations in size, form, habit, and habitat, in the forest society. The forest teems with many kinds of algæ, fungi, lichens, mosses, ferns, herbs, undershrubs and other shade plants, epiphytes, etc., to say

nothing of the great variety of animal life. Some forests are more complex than others. Because of the great divergence of form, character, and work among the members of a forest society, it is one of the most interesting ones for study.

1008. Different kinds of forests.—We know that the constituents of a plant community vary. Not only is there variation in different years or periods, there is variation in different regions. Regions which are so widely separated as to show great climatic differences show great differences in the character of plant communities. The same is true of the forest. Each different climatic belt or region has its characteristic forest. For example, the forests of the Hudsonian zone in North America are different from those of the Canadian zone, and these in turn different from those in the Transition zone. The forests of the Rocky Mountains and of the Pacific coast differ from those of the Alleghanian, Carolinian, or Austroriparian areas, because there are natural barriers extending north and south in addition to the transcontinental biothermal barriers. Finally, tropical forests are strikingly different from those of other regions. Similar variations occur in the forests of other regions of the globe. The character of these forests depends largely on climatic factors. The character of the forest varies, however, even in the same climatic area, dependent on soil conditions, or success in seeding and ground-gaining of the different species in competition, etc.

1009. Thickets.—According to Schimper thickets belong to the woodland climatic type of vegetation (see Chapter XLIX). Thickets are dense formations of shrubs. Warming says they are the "unsuccessful attempt of nature to form a forest." Examples in our country are the thickets of willows, alders, hazels, etc., found in the eastern and northern parts of North America, and the "chaparral" in the southwestern United States in the arid regions. Here these "chaparral" thickets are often composed of the mesquite, mimosas, acacias, etc. The highest type of thicket, however, is developed in some of the tropical or subtropical regions, especially of Africa, where the climate is rather severe, there being a long dry season alternat-

ing with a rainy season. These thickets are very highly developed in the so-called "thorn woods" and are often impenetrable because of the very dense and intricate growth, often with a profuse development of thorns. In the southern Appalachians in North America very dense thickets are sometimes formed by

Fig. 496*a*.
Forest with chaparral, southwestern United States. (Bureau of Forestry, U. S. Dept. Agr.)

the rhododendrons, which here reach such a high development, especially R. maximum.

1010. General structure of the forest.—Structurally the forest possesses three subdivisions: the *floor*, the *canopy*, and the *interior*. The floor is the surface soil, which holds the rootage of the trees, with its covering of leaf-mold and carpet of leaves, mosses, or other low, more or less compact vegetation. The canopy is formed by the spreading foliage of the tree-crowns, which, in a forest of an *even* and *regular stand*, meet and form a continuous mass of foliage through which some light filters down into the interior. Where the stand is irregular, i.e., the trees of

different heights, the canopy is said to be "compound" or "storied." Where it is *uneven*, there are open places in the canopy which admit more light, in which case the undergrowth may be different. The interior of the forest lies between the canopy and the floor. It provides for aeration of the floor and interior occupants, and also room for the boles or tree trunks (called by foresters the *wood mass* of the forest) which support the canopy and provide the channels for communication and food exchange between the floor and canopy. The canopy manufactures the carbohydrate food and assimilates the mineral and proteid substances absorbed by the roots in the soil; and also gets rid of the surplus water needed for conveying food materials from the floor to the place where they are elaborated It is the seat where energy is created for work; and also the place for seed production.

1011. Longevity of the forest.—The forest is capable of self-perpetuation, and except in case of unusual disaster or the action of man, it should live indefinitely. As the old trees die they are gradually replaced by younger ones. So while trees may come and trees may go, the forest goes on forever.

1012. Longevity of the tree.—Trees, like nearly all organisms, pass through the stages of growth and senescence, and then die. What it is which inhibits the growth of trees at a certain stage, and later brings about death, is not known. The entire tree is surrounded by a layer of growing tissue (cambium). The branches and roots are extended in length by increase of this tissue at the "growing points," while the trunk, branches, and roots are increased in diameter by the growth of the cylinder of cambium underneath the bark, which adds each year a layer outwardly to the bark and a layer inwardly to the wood. Thus, each year, new embryonic tissue; new channels for conduction of food; new organs for absorption, for respiration, and for photosynthesis, assimilation, transpiration, reproduction, etc., are formed. For this reason some have suggested there is no reason why the tree should not live forever, barring accidents. But, when trees reach a certain height, increase in height ceases,

or is so slight as to be practically imperceptible. Here the tree may stand for a long time, but it finally dies. Some have suggested that certain natural forces inhibit or set a limit to growth in height, as wind for example. But trees in protected valleys do not go on increasing in height beyond the normal height for the species. Certain trees like the mangrove or banyan,

Fig. 496*b*.
Banyan tree moved in one direction by trade wind. The older portion of the tree is at the right.

which spread by branches growing down into the ground, may live indefinitely, but the older trunks finally die. The banyan tree in windy exposures develops to the leeward, and in time the old trunk may thus travel considerable distances. Trees finally die of "old age." In nearly all organisms growth is at first slow, then is accelerated, reaches a maximum, then the rate of growth declines, and finally ceases, when life may be maintained for years with no perceptible increase in size, but a gradual waste and lessening in energy and vitality, until finally death ensues. This is in the later stages often accelerated by parasitic organisms which take advantage of the weakened constitution, if the tree does not in the mean time fall before the force of the wind. Many trees live for several centuries. A few

trees are known which have lived several thousand years. It is said there is in Kent, England, a tree of the genus Taxus, 3000 years old; also that there are now living on the slopes of Mt. Ætna chestnut trees from which Homer might have gathered nuts; in southern Mexico there is an old cypress tree (Taxodium) believed to be about 6000 years old, and in the Cape Verde Islands an Adansonia of similar age. Another account states that this old cypress in Mexico is about 2500 years old. It is difficult to get accurate data concerning trees of such age, but in the case of the Big trees of California (Sequoia washingtoniana) data have been obtained by counting the annual rings of a number of trees which shows their age to range up to 4000 years.

II. Boreal Forests.

The Boreal forests of North America form transcontinental belts and according to biothermal lines are in two zones.

1013. Forests of the Hudsonian zone.—These are the northernmost of the forests, extending from Labrador to Alaska, reaching the farthest north of tree growth, and extending southward on the upper timbered slopes of the mountain ranges of the United States and Mexico. The trees are mainly spruces and firs, with here and there colonies and mixtures of birches and aspens. The conifers, especially the spruces, firs, and balsams, are better adapted to growing at low temperatures than other trees, and this is why we find them pushing so far into the cold of the north or that of high mountain altitudes. The leaves are small, comparatively thick, and with a thick cuticle which retards transpiration. This is necessary on account of the high winds, which increase the loss of water, and the cold soil, which retards absorption. The conical form of the tree distributes the weight of snow more evenly, so that the danger of breaking is lessened, while the tops offer less resistance to the wind, which is more severe in these regions. The higher mountain peaks in the northern Alleghanian and in the Rocky Mountains

are occupied by an arctic-alpine flora of mosses, lichens, heaths, etc., or the higher ones are snow-clad, while in the southern Alleghanies the highest mountains are often clad to the summit with spruces and firs (balsam). Mt. Mitchel, in North Carolina, the highest mountain (6711 ft.) east of the Rockies, is clothed to the summit with spruces and firs, while pines and deciduous trees are on its slope.

1014. Forests of the Canadian zone.—The forests of the Canadian zone are similar, but have some species which do not reach so far north as the spruces and firs, especially some of the pines, the hemlock, spruce, and deciduous trees, but the conifers outnumber the latter.

III. Austral Forests.

1015. The forests of the Austral region show greater variations and do not form transcontinental belts because of the barriers presented by the arid interior portion of the United States, the high Rockies, and probably because of the peculiar temperature conditions of the Pacific coast, where a "low summer temperature combined with a high sum total of heat" permits a wider range and mixing north and south of boreal and austral types.

1016. Deciduous forests of Alleghanian and Carolinian areas.—The highest development of the deciduous forest in North America is in the Austral region, principally in the humid Alleghanian and Carolinian areas of the same. In the former are the oaks, hickories, chestnuts, locusts, ashes, birches, aspens, the northern spruces, firs, hemlocks, pines, and other coniferous trees found farther south. In the latter are the tulip-tree or whitewood, cucumber-tree, persimmon, sweet gum, sourwood, chestnut oak, Spanish oak, and yellow and scrub pine.

1017. Autumn colors.—One of the striking effects produced by the deciduous forests is that of the autumn coloring of the leaves. It is more pronounced in the forests of the United States than in corresponding life zones in the eastern hemisphere because of the greater number of species. With the disintegration of the chloro-

phyll bodies, other colors, which in some cases were masked by the green, appear. In other cases decomposition products result in the formation of other colors, as red, scarlet, yellow, brown, purple, maroon, etc., in different species. These coloring sub-

Fig. 497.
Conifers overtopping broad-leaved, deciduous trees in the forest (New Hampshire). A "mixed" forest.

stances to some extent are believed to protect the nitrogenous substances in the leaf from injury. The colors absorb the sun's rays, which otherwise might destroy these nitrogenous substances before they have passed back through the petiole of the leaf into the stem, where they may be stored for food. The gorgeous display of color, then, which the leaves of many trees and shrubs put on is one of the many useful adaptations of the plants.

1018. Forests of the Austroriparian, or Louisianian, area.— There are two distinct types of forest: 1st. *The upland forest*, occupying the dry, higher ground, is characterized by the long-leaf and loblolly pines, the live-oak, magnolia, and palmetto. 2d. *The palustrine forest* occupies the swamps of the coastal plain of the South Atlantic and Gulf States, and the lowlands of the rivers, extending from Hampton Roads and Chesapeake Bay

Fig. 408a.
Cypress knees, Mississippi. (Photograph by H. von Schrenk.)

in southeastern Virginia, reaching inland for some distance along the principal rivers of the region, and then extending up the Mississippi River and its main tributaries to Missouri and southern Illinois and Indiana. In this area the seaward slope from early

times was slight, and the vegetation retarded the flow of water to a much greater extent than on a more pronounced incline. This, together with the effect of the sands in damming up to some extent the flow, has produced the conditions which have made this great swamp possible. Some of the characteristic vegetation growing in the area is especially effective in retarding the flow of the drainage water from the surface and higher elevations, the cane (Arundinaria), the bald cypress, the tupelo gum, in some places the mangrove, etc. The bald cypress in wet ground develops numerous erect "knees" (fig. 498*a*) from the roots, which serve the purpose of aerating the root system, and they also catch floating material.

1019. Forests of the Pacific transition area.—This is a majestic coniferous forest, in parts of Washington, Oregon, and California, due to the unusual conditions which prevail. The annual rainfall is very heavy. The principal trees are the Douglas fir, Pacific cedar, western hemlock, and Sitka spruce, whose trunks gain an average height of more than 200 feet. Altogether in Washington and Oregon there are 27 different species of coniferous trees. Some of those not mentioned above are the western white pine, the giant redwood, and the Big trees of California. Broad-leaved trees, as maples, birches, oaks, aspens, alders, madronas, western dogwoods, and different kinds of shrubs, many of them reaching the size of small trees, occur as undergrowth which often chokes the interior of the forest, while the forest floor in many places is carpeted with mosses and ferns.

1020. The redwood (Sequoia sempervirens) reaches a greater height than any other American tree,* but does not attain the age of the Big tree of the Sierra Mountains in California. The redwood is confined to a "narrow strip of the coast ranges 10 to 30 miles wide extending from the Bay of Monterey, Cal., to a short distance across the southern border of Oregon." On mountain slopes it reaches a maximum height of about 225 feet and 10 feet in diameter, while in the valleys, where soil and moist-

* According to R. T. Fischer.

ure conditions are better, it attains a height of 350 feet by 20 feet in diameter. When the tree has reached the age of 500 years it usually begins to fall off in growth and die downward from the top. The oldest redwood found by the investigations of the United States Forestry Division in 1899 and 1900 was 1373 years old. Lumbering the redwood is now confined to the northern counties in California; the stands in Santa Cruz are

Fig. 498*b*.
Mature forest of redwood (Sequoia sempervirens). (Bureau of Forestry, U. S. Dept. Agr., Bull. 38.)

to be made up into a park, while smaller stands are left in other portions of the range.

1021. The Big tree (Sequoia washingtoniana) now occurs in scattered groves along the west slope of the Sierra Nevada Mountains a distance of 260 miles from the head of Deer creek to the middle fork of the American River. There are now known only two main groves, and while in all there are several thousand sizable trees, the number of trees remarkable for their size does

Fig. 400.
The Big tree, Sequoia washingtoniana. (Bureau Forestry, U. S. Dept. Agr.)

not exceed 500. The trees range in height from 250 to 360 feet, and the larger ones from 20 to 35 feet in diameter, while the bark of the larger trees is 2 feet thick. They occur at an elevation of 4500 to 7000 feet. They do not occur alone, but the other principal trees of the forest mixed with them are the pitch-pine, sugar-pine, Douglas spruce, white fir, and bastard cedar.

1022. Geological history of the Big tree.—Evidence of fossil specimens collected in Alaska, British America, Iceland, Greenland, Spitzbergen, Europe, and the Rocky Mountains in the United States shows that several species of the Sequoia existed in the Miocene period, and one of these, the Big tree, must have grown in Greenland as well as in the lower latitude of Europe. During glacial times they were destroyed in Europe, probably because in their southward migration they could not pass the barrier of transcontinental mountain chains in southern Europe, while they were permitted in North America to migrate south of the extent of the cold wave and thus were saved from extinction.

1023. Preservation of the Big trees.—The greater part of the Big trees are owned by private interests or by lumbering companies, but the U. S. government owns and controls in large part two large areas within the Sequoia and General Grant National Park, while the State of California owns one tract, the Mariposa Grove, an area of about two miles square, which is held as a State park.

IV. Tropical Forests.

1024. Kinds of tropical woods.—According to Schimper the woods in the tropics are divided into three groups: 1st. *The evergreen forest*, which occurs in the areas of great rainfall where there is no dry period. The woods are hygrophile in character, are at least 30 meters high, and usually much higher. Besides the forest trees there are numerous stout lianas, i.e., climbing trees and vines as well as woody and herbaceous epiphytes. 2d. *Mon-*

sun woods occur in those regions of considerable rainfall, but with a dry period, during the latter part of which the trees are bare of leaves. The woods, therefore, are markedly of a tropophile character, resembling in this respect the deciduous trees which lose their leaves during the winter period. The trees are less in height than those of the evergreen forest, are rich in woody lianas and in herbaceous epiphytes, but poor in woody epiphytes.

3d. *The savanna woods and the thorn woods.* These are rarely evergreen during the dry period. The savanna woods are about 20 meters high, are poor in undershrubs, lianas, and epiphytes, but rich in grasses and other herbs growing on the ground. The thorn woods as well as the savanna woods are xerophile in character, very rich in undershrubs and slender-stemmed lianas, are poor in herbs and grasses, and mostly without epiphytes.

1025. The evergreen tropical forests.—These are remarkable for the great number of species and of individuals, and for the great mass of vegetation. There is usually such a dense growth of tall forest trees that the light is shut out from the forest floor and interior to such an extent as to largely prevent the growth of smaller vegetation upon the forest floor. The forest is therefore noted for its epiphytes, herbaceous as well as woody, which grow in great numbers upon the branches, within or just beneath the forest canopy, where they are better situated in reference to light. It is interesting to note that in the reforestation of the volcanic areas in west Java, for example, a number of these epiphytes are found growing on the bare lava, among ferns and other low vegetation. Here they have a suitable relation to light, but when the forest finally develops in such regions, as it will if undisturbed, these epiphyte species now growing on the ground will migrate to the forest canopy. The evergreen broad-leaved forests are largely within the tropics, though there is some extension into parts of the south temperate region. While the forest represents the climax type of vegetation, the evergreen forest of the tropics is the climax type of forest formation. The evergreen tropical forests are found in those tropical areas where the rainfall is very great and is also evenly distributed throughout

the year, so that soil moisture and atmospheric humidity, while showing some variations, are relatively high throughout all seasons. This with the high degree of heat maintained throughout the year provides most favorable conditions for rapid and continued growth.

1026. Absence of climatic periodicity in evergreen tropical forests.—The absence of climatic periodicity in these ever-damp tropical areas is most striking in its effect on the general character of the vegetation as compared with those tropical areas where climatic periodicity is present, i.e., a dry season extending over a considerable period and alternating with a rainy season, as well as the climatic periodicity in the temperate regions, where a cold season alternates with the warm growing season. The more striking effects are, 1st, almost continual growth; 2d, the absence of bud-scales on the buds, since there is no austere season when these are needed to protect the young growing part, as is the case in the dry tropical or subtropical areas, or during the cold season in temperate and arctic regions; 3d, absence of uniformity in the time of defoliation: since there are no climatic changes which necessitate uniformity, a tree sheds its leaves and in a few days puts out a new crop; 4th, an extended flowering and fruiting period for many species, so that flowering and fruit-bearing often overlap in the same tree, though this does not continue throughout the year; 5th, a very dense forest canopy because of the favorable conditions of growth and the large size and number of the leaves making the interior of the forest darker than in any other forest areas, thus lessening the proportion of herbage on the forest floor; 6th, there is a relatively small amount of humus, the high degree of heat and moisture favoring rapid decay of fallen leaves and wood; 7th, in the many structures for protection of leaves against excessive wetting and the beating of heavy rains; a thick cuticle and often hairy leaves are examples of adaptations, while some interesting cases are known where the upper side of the leaves is furrowed along the line of the veins, these uniting and converging on the margin into a "gutter" which terminates on the external midrib at the leaf tip, forming a drainage system for

the leaf surface. Then the leaves of most tropical plants are thick and firm, as in the rubber plant, banana, orchids, bromelias, tillandsias, palms, etc., which afford them protection against the beating action of heavy and prolonged rains. 8th, against excessive heat and insulation, leaves of trees are protected by a vertical position of the highest ones, while those lower in the canopy are horizontal.

1027. Competition in evergreen tropical forests.—Thus climate is largely eliminated as a factor in the plant's struggle for existence. Plants are left to compete among themselves for space on the ground, space in the air, and for light. This competition has reached its highest pressure in the evergreen tropical forest. In all forest societies trees have outdistanced their rivals in the struggle for space and light. This is because of their height, by means of which they are enabled to reach above and beyond other plants. They overcome their rivals by casting a shade over them in which they cannot grow, or at least only preserve a miserable existence. Only plants tolerant of shade can grow beneath the forest canopy, and these rarely become successful rivals of the trees. The most dangerous competitors of trees under such circumstances are parasites and epiphytes and lianas.

1028. Epiphytes in the evergreen tropical forest.—In all forest societies epiphytes are present, but they have reached their climax in size, numbers, and effective rivalry with forest trees, in the evergreen tropical forest. The darkness of the interior of the forest largely prevents the development of even tolerant shade plants on the forest floor. Undershrubs and herbs have, as a consequence, migrated from the forest floor to the forest canopy, where they are crowded in surprising masses in tier after tier upon the trunks and branches, even to the upper extremity of the same; while on the uppermost leaves mosses, algæ, and lichens abound, as well as on the leaves and branches lower down. Numerous orchids, ferns, bromelias, tillandsias, and shrubs load the trees down in some cases with such a weight that the branches or tree are broken down. Where there are open places in the

stand of trees the admitted light encourages a luxuriant growth down the interior and even on the forest floor.

1029. Lianas in the evergreen tropical forest.—Lianas are climbing vines or trees. Lianas occur in forests of temperate regions, but they attain their highest development in the tropics.

Fig. 500.
A liana in the Botanic Garden at Peradenyia. (After Schimper.)

In size they vary from the more slender serpent-like twining stems to immense trunks, coiled on the ground and around the boles of forest trees, where they branch and ascend in tangled masses into the forest canopy.

1030. Value of tropical forests.—The forests of the tropics are of vast extent, and fully one half of the area covered by them has hardly been explored. Many of the woods are of very great value In regard to the Amazon basin, Agassiz says, "Nowhere in the world is there finer timber, either for solid construction or for works of ornament." A number of things have stood in the way of the exploitation of the tropical forests, chief among them being the climate and the great luxuriance of the forest itself; it is very likely that in the future the work of exploiting the forests of the tropics will be greatly developed. Many useful products are derived from a large number of different kinds of tropical trees. (See Gifford, Practical Forestry.)

V. Relation of Forests to Rainfall.

1031. Forests do not materially increase rainfall of a region.—In a study of the climatic vegetation regions it is clear that the forest is dependent on rainfall, and below a certain minimum annual precipitation, not very definitely determined, forests will not develop, and of course the rainfall must be rather evenly distributed throughout the year, or at least through the growing season. But that the rainfall of a region is influenced by the forest to any great extent, as is often supposed, is not so evident. Long-continued droughts during the growing season which occur now and then, and the great accompanying forest fires, show the inability of the forest to produce rainfall *per se*. Rainfall is due to moisture-laden air-currents from warm bodies of water coming in contact with the cooler air of coast lines, mountain chains, or cooler air-currents from colder regions. The movement of these air-currents is controlled by barometric pressures, a storm center originating in an area of low barometric pressure and moving to one of high pressure. But forests do account to some extent for a certain per cent of the rainfall of the region. The forest floor holds back a large amount of the precipitation of moisture-laden air coming from a distance. Through transpiration the forest leaves as well as those of other vegetation, together with evaporation from the forest floor and streams, load

the air with vapor. In mountainous countries where we can obtain a bird's-eye view of large forest areas, it is a common and interesting sight to see the cloud formation. Here and there, as the invisible water-vapor rises and comes in contact with the cooler air, one can see forming clouds of white mist in the morning which grow in size as they rise, unite with others, become more dense and center around and obscure some large mountain peak as they change into black "thunder-clouds," then move and precipitate their moisture over valley and mountain in the afternoon. Even when the air is not cool enough to cause precipitation of the moisture, the mist coming in contact with the cool surfaces of leaves, twigs, and branches condenses into water which drips from their surface.

1032. Importance of the forest in the disposal of rainfall.—The importance of the forest in disposing of the rainfall is very great. The great accumulation of humus on the forest floor holds back the water both by absorption and by checking its flow so that it does not immediately flow quickly off the slopes into the drainage system of the valley. It percolates into the soil. Much of it is held in the humus and soil. What is not retained thus filters slowly through the soil and is doled out more gradually into the valley streams and mountain tributaries, so that the flood period is extended, and its injury lessened or entirely prevented, because the body of water moving at any one time is not dangerously high. The winter snow is shaded and in the spring melts slowly, and the spring freshets are thus lessened. The action of the leaves and humus in retarding the flow of the water prevents the washing away of the soil; the roots of trees bind the soil also and assist in holding it.

1033. Absence of forest encourages serious floods.—The great floods of the Mississippi and its tributaries are due to the rapidity with which heavy rainfall flows from the rolling prairies of the west, and from the deforested areas west of the Alleghany system. The serious floods in recent years in some of the South Atlantic States are in part due to the increasing area of deforestation in the Blue Ridge and Southern Alleghany system. The

effect of floods from heavy rains there is evident to one who drives for 50 to 100 miles through the mountains, where valley roads become torrential streams, harvested crops of wheat and oats and hay are swept into the rivers, while dwelling-houses and even the surface soil are not exempt from the same fate. On mountain slopes where the soil is thin, it is sometimes swept clean to the bare rock after deforestation. The suddenness with which the water now rushes down the mountain slopes from numerous rivulets and branches, and unites in the rivers, sometimes forms a huge wave of water 20 to 30 feet at its crest which rolls on across the coastal plains to the ocean, often carrying destruction to life and property along its course. To one who has not been in the Blue Ridge Mountains a good picture of the devastating work of floods following the partial deforestation of these mountains can be gained by consulting the Message of President Roosevelt to Congress, recommending the establishment of a southern Appalachian Forest Preserve. The aggregate damage from floods along the southern Appalachian streams in the year 1901–02, reached the sum of $18,000,000.

VI. Forest Regeneration and Protection.

1034. Regeneration of forests.—If the forest is to be perpetuated there must be *regeneration*, or in time all the trees will die and the forest thus become extinct. *Natural regeneration* takes place in two ways: 1st, through the seed; and 2d, by the growth of sprouts from the stump when the tree is cut, or from the roots. These sprouts are called *coppice*. Trees which are shade-endurers are apt to have the advantage in the natural regeneration of the forest. The hemlock spruce, for example, is a shade-endurer, and thus the seedlings and young trees in the forest stand a good chance of coming to maturity. The redwood (Sequoia sempervirens) is a light-demander and so natural regeneration by seed is difficult except in open places. The redwood, however, develops abundant coppice, and the great amount of nutriment in the roots of the large trees supplies it

with an abundance of food, so that it grows rapidly, the stems often becoming quite tall, and the young trees remaining white except for a small crown of green leafage at the top. The Big tree (S. washingtoniana) regenerates by seed, and while not a

Fig. 501.

Abandoned field, Alabama, self-reforested by pines. (Photograph by Prof. P. H. Mell.) A Coniferous Forest Society.

great shade-endurer, enough seedlings survive to provide a succession of different ages where lumbering is not practiced.

Very few of the other conifers can develop effective coppice. They are dependent on the seed for natural regeneration. On the other hand broad-leaved trees develop abundant coppice, and in this respect have the advantage over conifers which are

not shade-endurers or do not develop coppice. Broad-leaved trees are limited, however, in their competition with conifers on

Fig. 502.
Coppice from redwood showing sprouts 6 to 8 years old. (From Bull. 38, Bureau of Forestry.)

thin sandy soil, and in cold regions, because many species of the latter can grow with a lower sum total of heat.

1035. Artificial regeneration of forests.—This is accomplished by the aid of man, and is one of the lines of forestry work which we call *silviculture*. This work may vary in intensity all the way from leaving a few seed-trees in the forest here and there, when cutting out the merchantable timber for self-seeding, to the complete reforestation of completely deforested areas. The extent to which artificial regeneration of forests can be successfully undertaken from a business standpoint will depend upon the condition of the forest, the price of lumber, expense of oper-

ation, and cost of marketing. It is the province of forestry to educate for, as well as to practice the principles of, economic harvesting and cultivation of forest crops, as well as the encouragement of forest protection and planting where necessary for the welfare of the race.

1036. Systems of management in cutting and regeneration of forests.—Several systems of forest management have been developed which are expressed briefly by Gifford as follows:

I. "The selection system, which is especially adapted to uneven-aged or irregular protection forests.

II. "The system of clear-cutting and then regenerating by planting with young trees, or by sowing the seed, or by waiting until the wind sows it from an adjoining forest.

III. "The system of regenerating pure forests naturally by uniformly and gradually thinning throughout, and admitting light in such a way that the seeds will germinate and the young growth properly develop.

IV. "The coppice system, where the forest consists of species which will sprout from the stump or the root."

1037. Protection of forests.—The fact that forests have an important influence in regulating the movement and disposal of rainfall has led the National Government and several State Governments to adopt forest policies and to set apart certain forest areas, especially in mountainous districts, as reservations, where lumbering is prohibited by law and efforts made to regenerate the forests where necessary and protect them from fire. The value of these forest reservations is, 1st, the protection of game and other wild animals; 2d, holding in reserve water-storage for power, as well as for city supplies; 3d, the protection of the valleys and lowlands from destructive floods; 4th, the providing healthful resorts where people find rest from the busy and exacting professional and business lives. When the principles of forestry are better understood by the people the reservations will probably be cropped and regenerated according to some suitable system which will not lessen their value for the purposes for which they were first set apart, and at the same

time will yield the state a revenue sufficient to more than pay for the cost of management, and also will tend to keep within reasonable bounds the price of building materials.

1038. Forest planting in unforested areas.—Successful attempts have been made to grow forests in the prairie regions of the West (the "plains" east of the 100th meridian) by transplanting seedlings and cultivating them and protecting them until they are large enough to shade the ground and hold their litter. These forests provide their owner shelter for orchards, provide fire-wood, fence-posts, and some lumber for building material. In Gascony (France) an arid, sandy area was planted with pines to hold the sand. The swamp regions here were also reclaimed by planting forests. What was once an unhealthful area is now a health-resort. Certain species of eucalyptus which grow in wet ground have been planted in swampy lands to drain them. This tree requires a great amount of water and transpires large amounts.

1039. Enemies of the forest.—Outside of the destructive injury of fires, wind, or the careless operations of man, as well as climatic and soil factors which are inimical to forest development, mention should be made of biotic factors. Many forms of life interfere with the perfect development of trees or act as destructive agents. Insects feed upon and destroy leaves, branches, and trunks; herbivorous animals feed upon foliage, buds, and twigs. We are concerned here chiefly, however, with plant enemies. These are parasites and wood-destroying fungi. The most important parasites are among the fungi, though some seed plants, like the mistletoe, "beech drops," "pine sap," arceuthobium, etc., do slight injury to some trees. The parasitic fungi injurious to trees are found among the rusts, mildews, molds, and a few among the mushrooms, black fungi, and cup fungi. The fungi, however, which are more destructive to timber trees are chiefly found among the mushrooms and their near relatives. They are known as "wound" parasites and wood-destroying fungi. It is quite easy in many cases for one possessing no technical knowledge of the subject to read the

Fig. 503.

Wood-destroying fungus (Hydnum septentrionale) on living maple, reduced $\frac{1}{7}$.

story of these "wood-destroying" fungi in the living tree. Branches broken by snow, by wind, by falling timber, provide entrance areas where the spores, lodging on the heart-wood of broken timber, or on a bruise on the side of the trunk, which has broken through the living part of the tree lying just beneath the bark, provide a point for entrance. The living substance (protoplasm) in the spawn exudes a "juice" (enzyme) which dissolves an opening in the wood cells and permits the spawn to enter the heart of the tree, where decay rapidly proceeds as a result. But very few of these plants can enter the tree when the living part underneath the bark is unbroken.

Fig. 504.
Spawn of the "mushroom" as it makes its way through the wood of the tree.

These observations suggest useful topics for thought. They suggest practical methods of prevention, careful forestry treatment, and careful lumbering to protect the young growth when timber trees are felled. They suggest careful pruning of fruit and shade trees, by cutting limbs smooth and close to the trunk, and then painting the smooth surface with some lead paint.

1040. Scavenger members of the forest societies.— While many of the mushrooms are enemies of the forest, "they are, at the same time, of incalculable use to the forest. The mushrooms are nature's most active agents in the disposal of the forest's waste material. Forests that have developed without the guidance of man have been absolutely dependent upon them for their continual existence. Where the species of mushrooms are comparatively few which attack living trees, there are hundreds of kinds ready to strike into fallen timber. There is a degree of moisture present on the forest floor exactly suited to the rapid growth of the mycelium of numbers of species in the bark, sap-

wood, and heart-wood of the fallen trees or shrubs. In a few years the branches begin to crumble because of the disorganizing effect of the mycelium in the wood. Other species adapted to growing in rotting wood follow and bring about, in a few years, the complete disintegration of the wood. It gradually passes into the soil of the forest floor, and is made available food for the living trees. How often one notices that seedling trees and shrubs start more abundantly on rotting logs.

"The fallen leaves, too, are seized upon by the mycelium of a great variety of mushrooms. It is through the action of the mycelium of mushrooms of every kind that the fallen forest leaves, as well as the trunks and branches, are converted into food for the living trees. The fungi are, therefore, one of the most important agents in providing available food for the virgin forest.

"The mushrooms also prevent the forest from becoming choked or strangled by its own fallen timber. Were it not for the action of the mushroom mycelium in causing the decay of fallen timber in the forest, in time it would be piled so high as to allow only a miserable existence to a few choked individuals The action of the mushrooms in thus disposing of the fallen timber in the forests, and in converting dead trees and fallen leaves into available food for the living ones, is probably the most important rôle in the existence of these plants. Mushrooms, then, are to be given very high rank among the natural agencies which have contributed to the good of the world. When we contemplate the vast areas of forest in the world we can gain some idea of the stupendous work performed by the mushrooms in 'housecleaning' and in 'preparing food,' work in which they are still engaged." (Atkinson, in Mushrooms, Edible, Poisonous, etc.)

CHAPTER LI.

THE PRAIRIE AND PLAINS SOCIETIES.

I. Grass-land Formations.

1041. Types of the grass-land.—Grass-land formations are of three general types: 1st, Savannas; 2d, Prairies or Meadows; 3d, Plains or Steppes.

1. *Savannas.*—This term is applied to the grass-land formations in warm temperate or subtropical countries where scattered trees or tree-clumps occur. The regions are too dry at certain seasons for the development of a woodland formation and yet not dry enough for the desert type. So grasses make the characteristic climatic formation. But there is sufficient moisture and absence of high winds to permit the development of numbers of trees.

2. *Prairie.*—The prairies (or meadows according to Schimper) are grass formations in the cold temperate regions where there is sufficient moisture to induce a close formation. They differ from savannas in the absence of trees. The high winds and very dry summer season prevent the development of trees.

3. *Plains (or Steppes).* The plains or steppes are grass-land formations principally, but usually the formation is more open because of the greater aridity of the climate. See paragraph below on extent of prairie and plains in the United States.

1042. Extent of prairie and plains region in United States.—The prairie vegetation region in North America extends over the arid areas of the austral region east of the Rocky Mountains,

extending into western Texas and Kansas in the south, and northward extending as far east as western Illinois. The area east of the Missouri River has a greater annual rainfall, and here is the typical prairie vegetation, which is of the meadow type. Passing westward and southward the region of the "Great Plains," or the arid region, is entered, where the rainfall is less and the vegetation is that of the steppes; while toward the foot of the Rocky Mountains southward the dryness of the region increases and partakes more of the character of the desert. The typical prairie region of North America extends from about the 100th meridian eastward to the forests of Illinois and Indiana, including most of the Dakotas, Nebraska, Iowa, southern Minnesota, and Wisconsin, a large part of Kansas and Indian Territory, and extends north into western Manitoba and nearly all of Assiniboia and Saskatchewan. The surface of the ground is rolling and furrowed, the prairie grass formation on the rolling elevations, with the so-called "gallery woods" or "park-like" forest societies at the lower elevations along the streams. This is the transition area from the forest area to the arid regions, or steppes.

II. Prairie Formations.

1043. Tension line between forest and prairie.—The tension line between the forest region and the prairie region was long since established. This line of separation is not well marked, for there is not an abrupt transition from forest to prairie. Arms of the prairie are outstretched now and then between extended troops of forests, and clumps of shrubbery and trees for some distance further dot the prairie here and there like sentries guarding the outposts of the main division.

1044. Climatic factors the dominant ones in limiting forest and prairie areas.—While the general climatic influences have been the chief factors in delimiting these regions, biotic or physical factors may in some cases have aided. For example, it has been suggested that the bison grazing on the prairies in central United States may have aided in preventing trees and shrubs

from getting a start. Also prairie fires may have destroyed them in the seedling stage. But it is quite clear that climatic factors have been the dominant ones. 1st. The greater amount of rainfall is in the spring and early summer, when the grasses of

Fig. 505.

Typical prairie scene, a few miles west of Lincoln, Nebraska. (Bot. Dept., Univ. Nebraska.)

the prairie most need it. 2d. This is the time when seeds of trees would germinate. Those enabled to start would die out during the drought of late summer and autumn. 3d. The firmness of the soil and dense mat of grasses would largely prevent seedlings getting a foothold in the ground. 4th. The heavy and drying winds during the dry season and winter cause excessive transpiration, and scatter the litter, thus preventing the accumulation of humus which is so necessary for the retention of moisture.

1045. Prevailing grasses in the prairie region.—Among the prevailing grasses in the prairie region are two types: 1st, the "sod-formers," long-stemmed grasses which make close formations, as the drop-seed (Sporobolus asperifolius), Koehleria

cristata, Eatonia obtusata, Panicum scribnerianum; 2d, the "bunch"-grasses, like buffalo-grass (Bulbilis dactyloides), beard-grasses or broom-sedge (Andropogon furcatus and scoparius), grama-grass (Bouteloua oligostachya), etc. These two types are more or less intermixed, but the "sod-formers" (="prairie-grass formation") are especially characteristic of the lower prairie areas, while the bunch-grasses (="buffalo-grass formation") are especially characteristic grasses of the arid region or steppes farther west and southwest. They make a close formation, but in the drier regions tend more and more to an open formation (see paragraph 1049).

III. The Plains Formations.

1046. The Great Plains of the United States.—The Great Plains, as the arid region of the United States is sometimes called, extend from about the 100th meridian to the eastern foot-hills of the Rocky Mountains, and they form a transition area from the prairie or meadow region to the desert area between the Sierra Nevada and western slope of the Rockies, the dryness of the area increasing in intensity toward the southwest. The prevailing grasses in this arid area are the bunch-grasses (buffalo-grass, beard-grass, Indian grass, etc.), which in the typical prairie usually grow in close formation, but here, while often forming meadow-like expanses, grow in more open formation. The other prevailing characteristic plants are the sage-brush (Artemisia tridentata), low, compact, tufted shrubs, grayish in color. The prickly-pear cactus (Opuntia) is also characteristic of the area, but is subordinate and less common, though it is the dominant plant over extensive areas. Reaching the Lower Sonoran area of the Great Plains there is a gradual change of the flora as the climate becomes hotter and drier in western Texas and New Mexico, where a semi-desert area (see paragraph 1054*a*) exists and extends into the high table-lands of Mexico, characterized by giant cacti, forming the so-called cactus deserts. Thus there are cactus societies (or cactus formations). Opuntia is common,

and here also occur the globose spiny forms called "pin-cushions," strawberry cacti, etc., of the genus Cereus, according to Bray, numerous yuccas (yucca formations), agaves, also coarse succulents, and coarse rough shrubby growths, like the mesquite (Prosopis juliflora), acacias, shrubby junipers, dwarf oaks, etc., which take the place largely of the bunch grasses and sage-brush of the Northern Plain's area, the shrubs and dwarfed trees often forming open or dense thickets known as "chaparral."

IV. Edaphic Formations in the Prairie Region.

The edaphic formations in the prairie region may be represented by some of those in the prairies and Great Plains of the western United States, as follows: the forest formations along the river courses, the meadows, the sand-hills, the alkali areas, and the Bad Lands of Nebraska and South Dakota.

1047. The forest formations along the courses of the streams are in some cases continuations of the great forest formations of the eastern United States, which reach far up the fertile and moist valleys of the larger rivers. In some cases the forests are more or less interrupted and scattered, where the valleys are narrow, or along smaller streams where they take on the form of "gallery woods" or "park-like" formations. The relation to the forest formations of the east is shown by the presence of many eastern species, as the black walnut, several species of oak, hickories, elms, paper-birch, etc. In the lower moist valleys broad-leaved deciduous trees prevail, while, in the higher and drier bluffs, is the xerophytic coniferous forest. While many species represent the invasion of elements from the eastern forest, others represent the eastern extension of trees from the Rocky Mountain region and the foot-hills. For example, the yellow pine (Pinus scopularum) in Nebraska along the Niobrara River meets and mingles with trees from the eastern forest (mingles with the black walnut, according to Bessey), or forms pure forests.

1048. Meadows.—These meadow formations (see Pound & Clements) are found usually along river courses and around lakes, and are intermediate between the forest formations and the prairie. They are characterized by long-stemmed grasses which are "sod-formers" (Elymus canadensis, Stipa spartea,

Fig. 506*a*.
Belt of forest bordering a stream in southeastern Nebraska. (Bot. Dept., Univ. Nebr.)

Agropyron pseudorepens, etc.). Some of the bunch-grasses occur as secondary grasses.

1049. The sand-hills.—The sand-hills in Nebraska represent dunes which have become fixed and are approaching a stable condition. The beard-grass (Andropogon scoparius), one of the bunch-grasses, is the dominant species, and, because of the severe dry conditions, makes an open formation, while on the sand plains another beard-grass (Andropogon furcatus), also a bunch-grass, is the dominant one, and the formation is closer, though sometimes open. The sand-plains thus represent, as we would expect, a transition from the true prairie areas to the more xerophytic condition of the sand-hills. What are called "blowouts" are formed by the wind where the sand-binding plants have been uprooted. They are similar to the troughs or gullies formed in other dune regions (see Chapter LIV).

1050. Subordinate to the bunch-grasses in the sand-hills are xerophytic shrubs, herbs, and other grasses. The sand-hills vegetation may be looked on as edaphic formations in the prairie

region. Since the grasses are the dominant species, they constitute the fundament of the formation. Other subordinate grasses occur, and besides, the prairie is variegated by annual and perennial herbs which give the formations, especially in the lower areas, a spring or vernal flora, as the cat's-foot (Antennaria campestris), fennel-leaved parsley (Peucedanum fœniculaceum), prairie clovers, etc.; and a summer-autumnal flora, as golden-rods, verbenas, amorpha, etc.

1051. The Bad Lands of Nebraska and South Dakota.—The vegetation in the "Bad Lands" is very meagre and is rendered so for several reasons: the alkalinity of the soil, which retards

Fig. 506*b*.

Bad Lands. Pinus ponderosa scopularum on the talus of buttes on the borders of Sowbelly Canyon, Pine Ridge, Nebraska. Bouteloua oligostachya (grama grass) formation in foreground. (Dept. Geol., Univ. Nebr.)

absorption by the roots; the loose and crumbling condition of the soil, which permits active erosion during rains and renders stability of any plant precarious; the very dry air and intense heat, inducing rapid transpiration; all these conditions well nigh prohibit plant life. The Bad Lands are situated in and near the foot-hills in the western part of these States. There

are pyramidal or conical, flat-topped hills (buttes) with very precipitous sides, and between them canyons. The sides of the buttes, cliffs, and canyons erode rapidly during rains. The characteristic plants are the greasewood, a spiny shrub (Sarcobatus vermiculatus) a meter (3 ft.) or less in height, and the white sage (Eurotia lanata), which also occurs on the high table-

Fig. 506*c*.

Big Bad Lands of South Dakota, an intervale with well-established vegetation of grasses, shrubs, and trees. (Dept. Geol., Univ. Nebr.)

lands, while a few bunch-grasses and herbs are rare or occasional wanderers from the outlying districts.

1052. Alkaline marshes and salt basins.—Here and there in the salty, alkaline basins, meadows are formed by the sod-grass, Distichlis spicata stricta, and Agropyron pseudorepens. In some of the very salty ponds in the basins, Ruppia occidentalis, in others the glasswort (Salicornia herbacea) grows, while in the salty soil around the basins certain chenopods (species of Atriplex), also the bugseed (Corispermum) and other halophytes occur, while farther out are the salty meadows of certain sod-grasses. Halophytes, of course, are able to flourish in a soil

or water with a concentration which would kill most mesophytes. Some plants adapt themselves to a much wider range in the chemical condition of the soil, for example, the chenopods, greasewoods (Sarcobatus), low, much-branched shrubs of radiate habit, spiny branches, and small linear, fleshy leaves, etc. These are plants which grow well in the so-called alkaline soils, and also grow in ordinary clay or loam soils. Some soils and waters are so strikingly different in chemical conditions that the vegetation is profoundly influenced.

CHAPTER LII.

DESERT PLANT SOCIETIES.

I. Characters of True Desert Plants.

1053. The true desert plants are the perennials which must preserve stem and root system through the hot dry period. They possess a habit and structure the result of the operation of physiological causes which enable them to exist during the severe season. They are *xerophytes*, and their structures are xerophytic, i.e., those which fit them for existence where the climate is dry, or where there is difficulty in absorbing water from the ground. In the desert this difficulty of absorption arises from the very small amount of water in the soil. Desert plants then have to meet two general conditions, a very dry and hot atmosphere and a very dry soil. This they do by provision for: 1st, reduction of transpiration; 2d, provision for water-storage; and 3d, increased surface for root-absorption.

1. *Reduction of transpiration.* — This is brought about in several ways: 1st, by reduction in size so that the leaves are smaller and thicker; 2d, by hairy coverings; 3d, the stomates are sunk deeply in the surface; 4th, the cuticle is thickened; 5th, the leaves are entirely dispensed with and the stems are green and function as leaves; 6th, the stems are shorter, and with a thick cuticle and often hairy or waxy coverings.

2. *Provision for water-storage.*—This is provided for by thick and often fleshy leaves, by fleshy stems as in the cacti, and often by a thick root system. Some of the cacti have large, rounded, globose stems. Some other plants have large, swollen bases to

their stems, and in others the roots are also much enlarged. These types with enlarged roots are rather rare in the Sonora-Nevada desert in the southwestern part of the United States, but are more common in southwestern Africa and in western South America.

3. *Increased surface for root-absorption.*—This is provided for by the great length of the root system and the profuse branching.

Fig. 507.
Desert vegetation, Arizona, showing large succulent trunks of cactus with shrubs and stunted trees. Open formation. (Photograph by Tuomey.)

In many desert plants the roots extend to great depths in the soils, where they obtain ground-water which is not so available nearer the surface.

1054. Thorny or spiny character of desert vegetation.—The development of thorns and spines on most desert plants is very striking. The cacti are remarkable for the great profusion of spines on the surface of their stems. The small leaves of many of the shrubs are sharp-pointed, and thorns are very characteristic of the shrubs of dry countries.

1054a. Conditions of environment in the desert.—We understand that the conditions of environment are very austere, so that plant life comes in sharp competition with the climate.

The principal factors are:

1st, the very low rainfall, varying from 8 to 10 inches, in some deserts, to 4 inches, or even less than 1 inch in some areas (see paragraphs 926, 928, 933, 1060).

2d, the great amount of evaporation during the long dry hot season; the amount of evaporation from the soil will depend on the character of the soil and the amount of ground-water, some soils conserving water more than others.

3d, the alternation of rainy and dry seasons, the rainy season in the temperate regions usually occurring during the cold part of the year, when plants cannot make use of it.

Some of the minor factors which might be mentioned are as follows:

1st, the strong light (solar radiation), especially during the warm season. This is due to the absence of clouds which form a blanket over the earth, not only cutting off direct solar radiation during the day, but which also check radiation of moisture from the soil both during day and night.

3d, high winds, which often sweep over desert areas, increasing the drying effect of the air on vegetation.

4th, the physical or chemical character of the soil often is such as to enforce a xerophytic habit for vegetation even if rainfall were greater; for example, salty or alkaline condition of the soil, calcareous soils in some desert or semi-desert areas, the loose and crumbling condition of soil in some regions which permits the rapid filtering away of storm- and ground-water, the topography of the region; also when very rolling or hilly, permits rapid run-off of storm-water.

II. The Sonora-Nevada Desert.

1055. In the valley between the Sierra Nevada and Rocky Mountains, including the Great Basin Ranges of Arizona, Utah, southern Nevada, and the southern part of California, etc., which is a part of the Sonoran arid area, a true desert condition exists, shown by the low annual precipitation, as well as by the dry hot climate and the great amount of water evaporated from the ground, though parts of it are intensified by the salt or alkaline basins, which would enforce a xerophytic habit irrespective of the dry hot climate. The desert areas are not determined alone by the low annual precipitation. A hot dry climate during a large portion of the year is an equally great factor. A district in the cooler portions of the north temperate zone with a low annual rainfall distributed through the growing season may furnish a luxuriant vegetation with no true desert vegetation. On the other hand, a district with an equal annual rainfall farther south, where the climate is hot and dry for a large portion of the year, and the rainfall is principally during the cold winter season, may have a true desert vegetation. In the dry hot season evaporation of water from the soil is very great. The Desert Botanical Laboratory of the Carnegie Institution, established near Tucson, Arizona, will give an opportunity, long needed, for more careful studies of the desert flora.

1056. In the "Death's Valley" (within the area of this desert) the true desert portions are quite distinct in vegetation from the areas bordering on ponds or streams, or from the basins where there is such an accumulation of water as to provide a sufficient amount of ground-water (hydrostatic water) to support a more luxuriant vegetation even through the dry season. These true desert portions are on the higher area, dry ground, and according to Coville are entirely devoid of hydrostatic moisture. All the water they receive is the storm-water during the rainy season which occurs roughly from December to March. The rains during this period amount to about 10 cm. (4 inches). The

water is absorbed and held by capillarity of the soil for a depth of perhaps several feet.

1057. The rainy-season flora thus appears in later winter and early spring. The seeds germinate along about February. When the rainy season closes the water held in capillarity by the soil begins to evaporate under the influence of the dry air and hot sun. The loss of this water is increased by transpiration of most of the water absorbed by the vegetation which has sprung up under the influence of the rains and warm spring. Sometimes in April the capillary water in the soil has all been withdrawn. The annual plants in the meantime, feeling the lessening amount of moisture in the soil, mature and ripen their seed, and then die, while the perennials prepare for the period of rest, by the loss of their leaves or the death of their aerial parts. They are sustained through the dry hot summer and autumn solely (Coville suggests) by hygroscopic moisture, i.e., that which the now air-dry soil absorbs during the night from the very small amount of moisture in the air. There are occasional summer storms (amount to about 3*cm* water), but usually so slight that the precipitation is immediately re-evaporated into the dry air. As the rains begin again in December a few of the perennials bloom, but the season is then too cold for most of the vegetation to flourish.

The annuals are the best adapted of any plants for the life in the desert, since the growth period is confined to the rainy season and the seed carries the life over the dry period and the cold of winter. The seed is practically the only adaptation for tiding the plants over the severe dry period, since the leaves are usually soft and thin and none are succulent. The adaptation is the same as many annuals in the cool temperate regions have for passing the winter.

1058. Sand-dunes in the desert.—In the Tularosa district of the desert in New Mexico, these drifting sand-dunes occupy an area of 10 by 40 square miles, and the sand here is composed of gypsum. These dunes reach a maximum height of 60 feet. The most characteristic plant of the dunes is the three-leaf sumac (Rhus trilobata). The cover afforded by the mat of branches and

leaves as well as the binding effect of the profusely branching roots often holds the sand in place in the form of tall columns as the wind moves the surrounding portion forward. Other characteristic woody plants are Atriplex canescens, Yucca radiosa, etc. This Yucca is sometimes buried by dunes and seems to have the power of growing out at the top again as it is buried from time to time with the increasing height of the dune.

1059. The true desert flora.—The shrubs have the compact rounded growth, and small, thick, gray leaves peculiar to most

Fig. 508.
Sage-brush (Artemisia tridentata), showing open formation in desert, Arizona. (After Schimper.)

perennial desert plants, since their relation is confined to the physical forces of environment, not at all to the organic, because the formation is an open one. The height of the shrubs is rarely over 1–1.5*m* (3–4½ feet), and is usually less. The sage-brush (Artemisia tridentata), one of the largest shrubs, barring accidents, never dies, for there are numerous shoots from the subterranean stock, and as the older ones die they bend outward and down-

ward while new shoots are developed. Peucephyllum schattii, on the other hand, is tree-like in habit, having a common trunk, and thus in old age dies. These two shrubs, according to Coville, represent the two types in the Death's Valley.

The perennial vegetation, aside from the true shrubs, is peculiar. Only a few species have enlarged roots for water storage during the dry season. In these the aerial stems die down to the ground. A large number of them, however, are suffrutescent, i.e., the lower portion of the aerial shoots is shrubby. These remain green, and slow transpiration goes on during the dry period, as in the case of the true shrubs, while the roots are not thickened for water storage, but find enough hygroscopic water to supply the reduced shoot system.

Fig. 509.
Desert society, chiefly yucca.

Cacti, Yuccas, etc.—Trees are not present in the true desert portions of the regions, while around springs or along streams, or in the vicinity of basins where there is ground-water through-

out the dry season, trees are present, especially the mesquite trees. Tree yuccas (Y. arborescens, etc.) occur on higher elevations, but not on the lower dry ground. These yuccas on the

Fig. 510.

Winter range in northwestern Nevada, showing open formations: white sage (Eurotia lanata) in foreground, salt-bush (Atriplex confertifolia) and bud-sage (Artemisia spinescens) at base of hill, red sage (Kochia americana) on the higher slope. (After Griffiths, Bull. 38, Bureau Plant Ind., U. S. Dept. Agr.)

mountain slopes are just beneath the coniferous forest line which forms a horizontal zone on the mountain slopes, marking the lower limit of snowfall in a very sharp manner from the lower zone of rainfall. The snow-storage here on the desert mountains provides a source of water which is doled out later in the season and permits the forest growth. The tree yuccas just beneath this forest probably get some of this moisture. Besides the plants mentioned above, cacti, salt-bushes (Atriplex), greasewoods (Sarcobatus), etc., occur. These all show the usual adaptations to desert conditions, reduced leaf and stem surface to check transpiration, and an increase of the root system for absorption. The extent to which the reduction of surface for transpiration is carried in desert plants and the corresponding increase of root system for absorption is shown by Coville in the case of a prickly-pear cactus examined. The aerial part con-

sisted of two branching stems 48*cm* (19 in.), which consist of cylindrical to flattened, pear-shaped, thick, succulent portions devoid of leaves, provided with a thick cuticle and large water-

Fig. 511.
Desert vegetation Arizona, showing clump of prickly-pear cactus in foreground with radiate shrubs in background. Open formation. (Photograph by Tuomey.)

storage system. There were eight roots with an average length of 2–3*m* (7–10 feet), each of which had numerous lateral branches.

III. Other Desert Regions.

1060. The greatest desert region in the world comprises the great Sahara Desert, which extends across the northern part of the continent of Africa between 20° and 30° north latitude, and then extends over Arabia, then southward over south Persia and Beluchistan and the northeast corner of farther India. The next in size is in central Asia, from the Caspian Sea to the mountains which separate Mongolia and Manchuria. The largest one in the southern hemisphere is in central Australia; there is a smaller one in southwest Africa, and a narrow desert

on the west coast of South America from 5° to 30° south latitude. The annual rainfall in these deserts varies, does not exceed 30*cm* (12 in.), while it is usually much lower, from 5–8*cm* (2–3 in.), and in one place in Chili it is as low as 1*cm*. In the great desert of north Africa, and its continuation in southwestern Asia, the annual rainfall is about 20*cm* (8 in.).

1061. Time of maximum rainfall.—The maximum rainfall occurs at different seasons in different deserts; for example, during the spring in Sahara, autumn in north Chili, summer in Australia. The rainfall is so slight that the vegetation periods (except the rainy-season flora) are independent of the maximum, but they are dependent upon temperature, and the austere period occurs during the hottest period of the year. (In Sahara the July temperature rises to 36° C. = 97° F.) According to Schimper the vegetation is more dependent on the ground-water than on the moisture from rainfall, though there is a general ephemeral rain flora in the spring. When the rainy season is over the green covering of the earth disappears, and the ground is as nearly devoid of plant life as before. Many perennials are also benefited by the spring rains, chiefly because transpiration is checked.

1062. Character of Sahara Desert.—The great desert of Sahara consists of elevated, furrowed, and stony plains, or rolling and stony lands, sandy lowlands, long sand-dunes, with here and there an oasis. Strange as it may seem, the places are rare where vegetation is not in sight from any point, but this consists of low, compact, shrubby plants in small clusters or streaks. The oases are populated by a rank growth of trees and herbs and parts of them are cultivated. The line between oasis and desert is closely drawn.

1063. Two ecological vegetation types in the desert.—The plants of the desert may be grouped into two ecological categories: the existence of the one is dependent directly on the rain-, the other on ground-water. 1st. To the first category belong the rainy-season plants. They germinate their seeds, grow, flower, and seed again during the period. There are also per-

ennials which at the same time develop foliage stems, flowers, and fruit during the rainy season, and then the exposed parts die and the subterranean rootstocks carry the plant through the

Fig. 511*a*.
Desert society, chiefly cactus, Arizona. (Photograph by Tuomey.)

dry period. 2d. The plants dependent on ground-water belong to the second category. They are all perennial and have perennial aerial shoots. They bloom during the dry cool weather.

CHAPTER LIII.

ARCTIC AND ALPINE PLANT SOCIETIES.

I. Arctic Plant Societies.

1064. The arctic zone of plant life extends from the limit of tree growth to perpetual ice and snow. The arctic zone is some-

Fig. 512.
Northern limit of tree growth, Alaska. (Copyright, 1899, by E. H. Harriman.)

times spoken of as the "cold waste," because in general there are some of the aspects of the desert in the character of the vegetation. The analogy, however, is not fully carried out because

the effect of environment is not wholly similar. The ground over a large part of the region is frozen to a great depth and only thaws out on the surface during the summer. This makes the ground-water usually very cold even during the summer.

1065. Character of tree growth.—The polar limit of tree growth is conditioned by drying winds in frosty weather. There is no sharp dividing-line between the forest and treeless waste, but there is a gradual reduction in the number of the trees, their size as well as their vigor. The formation becomes more and more open, the trees are reduced more and more in size, and are more and more disfigured by dead and dying branches and tops, and by dwarfing and warping out of shape as one approaches the true polar waste. The transition line is gradual, and the two climatic formations are mixed. Where the snows are not sufficient to cover the trees for several months during the winter the tops of the trees die, often at quite a regular distance from the ground. These trees often branch below and sprout from below and thus form broad expanded low crowns. Where the fall of snow is heavy the trees are often covered for several months

Fig. 513.

Polar limit of tree growth in Saghalin near Kamtchatka. Large trees stunted and showing horizontal growth. Induced by high wind and weight of snow. (After Schimper.)

during the winter. The snow bends the tops over and the tree grows more or less horizontally. The covering of snow and

their prostrate condition protect them from the drying effect of the fierce winds in the very cold weather. As one passes beyond the line of tree growth the trees and shrubs become greatly stunted and dwarfed. Growth in length of the stems takes place proportionally slower than growth in diameter, and yet even the diameter increases very slowly. For example, a dwarf tree 83*mm* ($3\frac{1}{3}$ in.) in diameter showed 544 annual rings!

1066. The polar tundra.—Tundra is the name given to a large portion of the polar waste. The tundra are related in their formation to heath or peat moors. Heaths, saxifrages, dwarf willow, and other dwarf shrubs abound. The forma-

Fig. 514.
Polar tundra with scattered flowers Alaska. (Copyright by E. H. Harriman.)

tions are often open, and the vegetation varies over different areas. In some places devoid of shrubs the tundra is covered with a growth of mosses and lichens, often the reindeer-moss (Cladonia rangiferina) being very abundant. So there are "moss-tundra" (chiefly the moss Polytrichum) or "lichen-

tundra" (formed of different species, sometimes Cladonia or Alectoria, etc.).

1067. Conditions of environment.—These are very peculiar to the region. 1st. *Temperature*, the extreme cold of the long winter and the low summer temperature. 2d. *Light*, the long winter night and the continued daylight of the short cool summer. The continuous light in the summer is an advantage, since photosynthesis goes on without interruption and food materials are

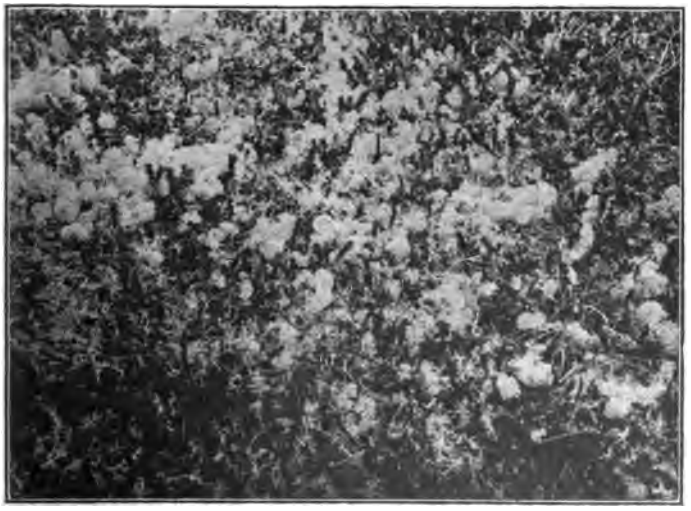


Fig. 514*a*.
Lichen tundra showing the "reindeer-moss" or lichen, Alaska. (Copyright by E. H. Harriman.)

constantly formed. 3d. *The cold ground-water* because of the ground-ice below the shallow layer of surface soil which is thawed out; this retards root absorption. 4th. *The high winds*, which in the cold dry climate are more trying for plants than the lower temperatures to which they are subject. 5th. *The very dry air* of the long winter. The long winter night is usually clear, there is but little precipitation, and the air is very dry, so dry sometimes during the severest cold that one's breath does

not condense. 6th. *The lessened precipitation*, so that the snow is not so deep except in colder regions where it does not all melt during the summer, but forms great glaciers or permanent snow-fields, which, of course, prohibit plant life except a few low organisms on the surface of the snow. In addition the high

Fig. 515.
Willows from Greenland, one third natural size.

winds often drive the snow from extensive tracts and leave them bare during the long winter night.

1068. Responsive type of vegetation.—The vegetation responds to these conditions of environment by the development of certain types of plants, as the radiate dwarf-cushion type, the rosette type, the succulents, etc. The succulents are plants with thick and fleshy stems and leaves for water-storage. These general characters are very similar to those of many desert plants. In plants with these habits there is less radiation of heat and moisture, and they are also protected better from the drying effect of wind. The leaves are either leathery, stiff, and hard, or small scale-like leaves with a thick cuticle, as in Cassiope, or

needle-like or succulent, as in the saxifrages. They are further protected from excessive loss of water by the stomates being

Fig. 516.
Perennial rosette plant from alpine flora of the Andes, showing short stem, rosette of leaves, and large flower. (After Schimper.)

sunk in cavities or covered with hairs or wax. The leaves of grasses resemble those of grasses of the arid region.

1069. Resistance to cold.—Besides these adaptations for lessening the transpiration, or for lessening the loss of water when the leaves are frozen, the plants have a specific power of resisting the cold which is probably to be found in some special condition of the protoplasm.

1070. Flowers.—In many of the arctic plants the flowers are very conspicuous. They are in general brighter in color than in the temperate or tropic regions. This brilliancy of color in the flowers has been noted by many arctic travellers. Then they are usually very large in proportion to the size of the stem and leaves, often large flowers being found on herbs, the stems of which are so short that the flowers are close to the ground. The summer being very short, the period for growth of vegetation is very short, from two to two and a half months, yet in this period there is ample time for flowering and fruit, since the plants, being perennial, can begin at once to form flowers in the early part of the growing season.

1071. Warm oases.—There are even "oases" in the desert-like tundra-wastes. These are known as "warm oases," situ-

ated where they are protected from the wind, and the slope of the ground is such that the sun's rays are nearly perpendicular to the surface. The ground is thawed out to a much greater depth and the ground-water thus becomes much warmer than in other places. This encourages a more luxuriant growth and the protection from wind also favors a taller vegetation. The result is that the vegetation in these places stands out in marked contrast to the usual vegetation type because of the height and luxuriance of the growth.

II. Alpine Plant Societies.

1072. Alpine plant societies occur on mountain heights where the change in temperature and other conditions of environment are so great as to produce a decided change in the vegetation type. Schimper treats of three zones of vegetation in the mountain regions as follows:

1. *Basal region*, where the vegetation is more hygrophile, and similar to that of the lower elevations of neighboring lowlands because of the increase in precipitation at the lower mountain elevation.

2. *Montane region*, where the vegetation is more hygrophile and less thermophile than in neighboring lowland, comparable to the vegetation of higher elevations of lowlands because of the increase in precipitation induced by the cool mountain region.

3. *Alpine region*, where the vegetation is influenced by an alpine climate, without analogy in lowlands. At this height precipitation has rapidly diminished and is less than in the lowlands. This alpine region corresponds to the alpine zone of the forest region, according to Merriam.

In passing from the base of mountains to the lofty summits, one passes rapidly through the different life zones corresponding to the change in climate, the forest formations showing changes similar to those seen in passing from the austral region northward to the arctic zone. As one passes upward beyond the tree-line or woodland formation, there appears a grass-land

or prairie formation which is a transition belt to the true alpine formation above and which is comparable to a desert formation because of the austere conditions which so limit plant growth. While there is a general resemblance between alpine and arctic vegetation, there is an essential difference in structure even of individuals in the same species. As a matter of history many alpine species are arctic species which were left behind as the continental ice-sheet retreated northward at the close of the glacial peroid. Bonnier has found that aerial parts of Salix polaris and Saxifraga oppositifolia are more weakly developed in polar than in alpine individuals, while polar plants in general have thicker leaves than alpine plants, but the leaves of polar plants show less differentiation in structure and larger intercellular spaces. So the present form and structure of alpine plants are not due to these historical causes, since alpine conditions are sufficient in themselves to induce the peculiar habit and in addition to induce changes in structure since the glacial period. These peculiarities of alpine plants are, therefore, due chiefly to physiological causes and not merely to heredity.

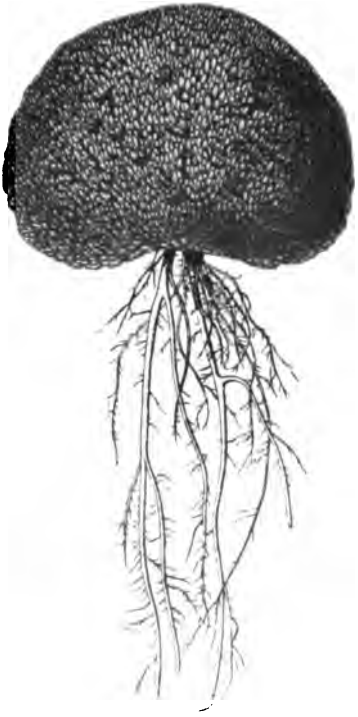


Fig. 517.
Compact, radiate cushion type of vegetation of North Polar region, Draba alpina. (After Kjellman.)

1073. Factors of alpine climate influencing plants.—These factors are: 1st, decrease in precipitation; 2d, decrease in heat (the temperature being very low); 3d, rarity of the atmosphere,

which favors, 4th, strong solar radiation, and 5th, strong radiation from the ground bringing about great changes in temperature between night and day; 6th, the high winds; 7th, alternation of night and day, there not being the continuous lighting present in polar lands, and 8th, alternation of heat and cold during the growing season, again very different from the arctic summer.

1074. Characters of alpine vegetation.—The characteristic alpine vegetation lies above the limit of tree growth, which often

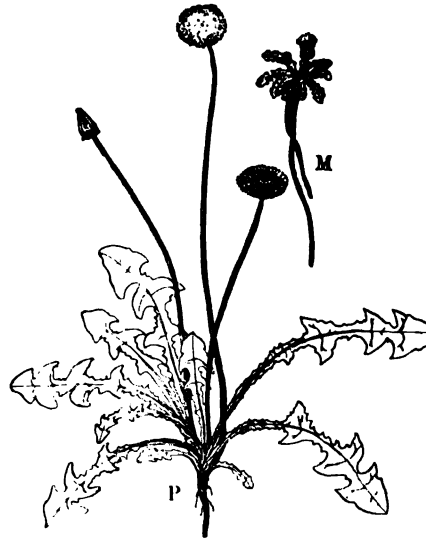


Fig. 518.

Perennial rosette plant, dandelion. *P*, lowland culture; *M*, alpine culture proportionately same size, but showing difference in length of stem, leaves, and the larger root of alpine plant. (After Bonnier.)

forms a very distinct line on the mountainside. The vegetation forms are similar to those of the arctic zone: the stems are short, the leaves smaller, forming rosettes near the ground, or scale- or needle-like and adpressed close to the stems. The leaves are also thicker, often protected with a thick cuticle or by a covering of hairs, and the structure of leaves and stems is xerophile. The roots are usually much more strongly devel-

oped. The flowers are often large in comparison with the stems and leaves and have usually bright colors. Trees and shrubs are dwarfed and stunted. These as well as much of the other vegetation are compactly branched and of the rosette or radiate type. The mosses form dense, deep, and extensive cushions.

1075. Types of alpine plants.—Schimper distinguishes the following types: 1st. *Elfin tree.* This type has short, gnarled, often horizontal stems, as seen in pines, birches, and other trees growing in alpine heights. 2d. *The alpine shrubs.* In the highest alpine belts they are dwarfed and creeping, richly branched and spreading close to the ground, while at lower belts they are more like lowland shrubs. 3d. *The cushion type.* The branching is very profuse and the branches are short and touch each other on all sides, forming compact masses (examples: saxifrages, androsace, mosses, etc.). 4th. *Rosette plants.* These are perennial, with short stems and very strong roots, and play an important part in the alpine meadows. 5th. *Alpine grasses.* These usually have much shorter leaves than grasses of the lowlands and consequently form a low sward.

1076. Variation of individuals of same species in alpine regions and lowlands.—It is believed that some species have a very wide distribution so far as elevation is concerned, so that some individuals of a species grow in the lowlands and valleys, while other individuals grow also in the alpine region. But the form of the plants in the two widely separated regions is so different that they are usually regarded as distinct species. Experiments have been made (especially by Bonnier) in transplanting alpine plants to the lowlands. In some of these experiments single alpine individuals were divided, one half taken to the lowlands and the other half kept in the alpine regions, while the soil used in both cases was taken from the lowlands. In a few years in a number of cases the halves of individuals transplanted to the lowlands took on the form of lowland species which were supposed to be the same, while the halves kept in alpine climate underwent no change. This shows that at least some of the peculiarities of alpine plants are due to the alpine climate.

CHAPTER LIV.

THE VEGETATION OF THE STRAND.

I. Types of Strand.

1077. Strand formations are usually so strikingly different from other edaphic as well as from climatic formations that they may be considered in a separate section. By the strand, or beech, flora is meant the plant life growing along shores of the water, usually lakes or seas. There are two general types of strand, conditioned by the water-holding capacity of the soil. These are the *xerophytic*, or dry strand, and the *hydrophytic*, or moist strand. During surf action or rains the dry strand is wet, but in the sandy soil the water leaches out quickly and also evaporates rapidly from the surface, while on rocks the water runs quickly off. Radiation of heat takes place more rapidly also from a sandy soil than from a nitrophytic soil, i.e., one with an abundance of humus. In the xerophytic strand the gradient of the slope is steeper, so that there is only a narrow zone of shallow water, or none, while in the hydrophytic strand the gradient is low, giving a usually broad zone of shallow water where the surf breaks before reaching the shore line. Here there is usually an abundance of aquatic vegetation, and some plants in this zone often act as surf barriers (certain species of Cyperus, the flags, etc.). Between these two types of strand, however, there are all gradations and modifications, so that for purposes of study a farther subdivision is desirable, and often different strands will have different composite elements, so that a

classification adapted in one case may not be so serviceable in another. For example, the action of surf on the strand formations will be different on the shore of a lake not frozen over during the winter, when the high winds carry the wave action higher up than in the summer. Ocean tides also tend to complicate the strand formations beyond what is seen on the shores of lakes or ponds. Along salt bodies of water also a halophytic type is developed on rocky shores and in salt marshes, and to a limited extent on the mid-strand sandy shores.

The flora of the strand bears a very close relation to its physiography, and can only be understood when studied in connection with the physical geography of the region,* and in an endeavor to trace the evolution of the plant formations, i.e., the part which plants have played in determining the physical geography of the strand, as well as the influence of environmental factors on the plant formations.

1078. Variations in the shore.—Variations in the topography of the shore offer very different conditions for plant life, so that a great variety of edaphic formations are developed. These variations take place in three general directions: 1st, the gradient of the shore, whether precipitous as shown in the bluff, or very high steep banks, or in the lower grades down to a gradual slope toward the interior country; 2d, the mechanical condition of the shore material, whether of solid, smooth-surface rock or creviced rock, boulders large or small, talus, gravel,

* MacMillan (1897) was the first one in America to apply this principle to the study of plant formations. (See observations on the distribution of plants along the shore at Lake of the Woods. Minn. Bot. Stud., Vol. I., Bull. 9, 949–1023, May, 1897.) In concluding he says: "No extended summing up is necessary, for it must be apparent that the purpose of the paper has been but a single one—to point out the dependence, over such an area as the shores of the lake, of plant formations upon topographic and environmental conditions. It has been shown how each formation may be explained briefly as connected with a certain *mélange* of outward conditions both by themselves and as connected with the growth of the vegetation."

sand, humus, or morass; 3d, the percentage of humus. Variations in exposure to tides, wave action, drainage, and winds affect not only the topography of the shore, but also the development of the plant formations.

In general, then, there are three different kinds of strand as regards the physical character of the ground:

1st. Rocky shores, or Lithophytic.
2d. Sandy shores, or Psammophytic.
3d. Loamy shores, or Humiphytic.

The first two condition open growth of vegetation and approach the desert type, while the last one conditions a close growth.

The first and third types will be treated of under the head of the various rock and swamp societies (Chapter LV).

1079. Formation of sandy shores.—The sand of the sea or lake shores is formed by the action of the beating waves or currents on rocky shores; or the grinding action of rocks on the beds of streams or under moving glaciers. From streams this is washed down to the seas or lakes, where, if the shore is not too precipitate, it is deposited where the wave action may throw it up on the shore and form the sandy beach. So wave action on rocky sea or lake coasts grinds the rock down into sand in places, which is again washed up on the shore to form the sandy beach. When the sand accumulates on the shore, at the upper edges, during calm periods of the water, it dries out and then is easily swept inland by the wind, when it forms fields or hills of sand known as sand-dunes. The vegetation of sandy shores can then best be studied under two heads: 1st, the vegetation of the beach or strand; and 2d, the vegetation of sand-dunes.

II. The Vegetation of the Beach or Strand.

1080. Divisions of the strand.—Sandy shores are sometimes spoken of as the true strand, or beach. There are certain natural divisions in the topography of the beach, due largely to the action of the water, and parallel with the coast line, and the plant formations are found to bear a distinct relation to these

divisions. Schimper divides the ocean strand into three parts: 1st, the fore-shore (*Schorre*), the area covered by the tide between ebb and flow, and in sandy shores devoid of vegetation; 2d, the mid-shore, above the flood line of the tide; 3d, the *dunes*, the sand-hills toward the interior. A different division is made of the strand formations of Lake of the Woods by MacMillan as follows:

1st. The *front strand*, being that part of the strand next the water, upon which the surf washes during the ordinary winds of the season. 2d. The *mid-strand*, an area parallel with this, but farther up on the beach and acted upon by the surf at greater intervals during very high winds. At Lake of the Woods these high winds are believed by MacMillan to occur once in several years. 3d. The *back strand*. This is developed by the activity of the wind rather than by the ice or surf, and may represent in some cases a higher level of the lake. 4th. *Strand pools*, hollows where water accumulates either from surf or from rains. 5th. *Dunes*, hills of sand formed by the wind driving the sand, which is caught and held by plants. Some use a slightly different terminology, as follows:

1st. *Lower beach* (=front strand); 2d, *middle beach* (=mid-strand); 3d, *upper beach* (=back strand); and 4th, *dunes*.

1081. The lower beach, or front strand.—This being frequently washed by the surf prevents the permanency of any vegetation. Seeds of plants may germinate, but waves wash the seedlings away. The only plants which develop here are those which can pass through the period of growth and fruiting in a short while. Thus lower algæ, especially members of the *Cyanophyceæ* (blue-green algæ), are often found here in small pools which are fed by the surf. If the water remains quiet for some time, the pool may dry, but the plants are tided over the dry period by their spores (Nostoc, Anabæna, Oscillatoria, Lyngbya, etc.).

1082. Middle beach.—This corresponds to mid-strand, and represents the zone acted upon at longer intervals by the surf, generally during the winter at the time of higher winds. The

conditions are severe because evaporation of water and radiation of heat are rapid. The vegetation is, therefore, sparse, scattered, and xerophytic. Characteristic sand plants along Lake of the Woods, like certain grasses (Agropyron tenerum, Elymus canadensis) and other sand herbs (Artemisia caudata and canadensis), are among the first to gain a foothold, and species in these genera are found in similar strand formations on the Great Lakes and on the Atlantic and Gulf coasts. These assist in the formation of humus and in holding it, and soon other plants appear. The formations vary greatly according to variations of soil and exposure. Thus one with considerable wind exposure has as a dominant plant, a low shrub with small leaves, *Prunus pumila*, the sand-cherry (Prunus formation), with subordinate species of a similar habit, as well as sand grasses and herbs. Another formation with less wind exposure and a less per cent of humus has a taller shrub with broader leaves as the dominant plant and is a Cornus formation. In still another where inundation is frequent and the plants would be more liable to be torn out, certain dwarf willows which are low, small-leaved and deep-rooted are dominant, and this is the Salix formation, and so on. While all these formations are adapted to severe conditions, each one presents peculiar types of austere conditions and is populated with dominant plants which present special adaptations to specific conditions.

On the east shore of Lake Michigan the dominant plant is a crucifer, American sea-rocket (Cakile edentula), while two others are common, bug-seed (Corispermum hyssopifolium) and sea-side spurge (Euphorbia polygonifolia). The Cakile and Euphorbia are characteristic also of the beach on the Atlantic coast, while on the Gulf coast or island shores of Mississippi and Louisiana low succulent plants with radiate habit of growth occur. There is here a seaward zone of sea-blite (Dondia linearis), sea-rocket (Cakile fusiformis), saltwort (Salsola kali), sea-purslane (Sesuvium maritimum), large burr-grass (Cenchrus macrocephalus); and a landward zone of the same with tropical morning-glories (Ipomoea pes-capræ and I. acetosæfolia) trailing on the

ground for 30*m* or more, the trailing wild bean (Strophostyles helvola). These trailing morning-glories occur on the beach in tropical regions of South America. For protection against strong insolation (excessive heat) the blade of the leaves is brought into a vertical position. The trailing wild bean, on the other hand, extends as far north as Quebec and west to South Dakota, Nebraska, and Texas in sandy soil. The sea-rocket and salt-wort also extend northward along the middle beach of the Atlantic coast of the United States.

1083. The upper beach is the third parallel zone and corresponds probably to the back strand. This is beyond the reach of the waves, and perhaps in some cases represents a former portion of the beach acted upon by the surf, though it is principally developed by the activity of the wind. The limits of all of these zones are constantly changing, due to the action of the waves on the water side and of the wind on the landward side. Chemical and physical conditions of the soil are also different, there is a higher percentage of humus, shows darker color, evaporation and radiation are less, the soil water is nearer the surface, and the soil retains more heat. This encourages different biological conditions which are shown in the different character of the plants. Though sand is still the principal constituent of the soil, the characteristic plants are those which have more of a thermophytic or nitrophytic character. The conditions of plant life are less severe than on the middle beach. Still the vegetation is similar to that of sand formations, and the nitrogenous material is not so abundant as to encourage true humus plants like Corallorhiza or Pyrola. The vegetation of the upper beach may also be divided into several formation groups according to certain soil characters, and these again are still further subdivided according to areas which encourage certain dominant types of plants, whether herbaceous, shrubby, or arboreal, and these further into the individual formations. According to Cowles the most characteristic species of the upper beach on Lake Michigan are: 1st. *Grasses and other herbs.* Artemisia caudata and A. canadensis, while these are often associated with Cnicus

pitcheri, Lathyrus maritimus, which is also a marine beach plant, Euphorbia polygonifolia, Œnothera biennis, and Agropyron dasystachyum. 2d. *Shrubs.* Of the shrubs the common ones are the sand-cherry and a species of willow which have been noted on the mid-strand of Lake of the Woods. 3d. *Trees.* Of trees the cottonwood occurs, the Populus monolifera southward and Populus balsamifera northward.

1084. Wide distribution of beach plants.—The full list of even some of the most common species characteristic of the different strand zones cannot be given here, but it is interesting to note that while some beach plants have a very wide distribution, occurring throughout the length of the Atlantic coast and on the shores of the Great Lakes, others have a less extensive distribution, so that in the tropical and subtropical regions, for example, areas occupied by certain plants in the boreal and austral regions are occupied by entirely different plants. Thus, in the tropics, Spinifex squarrosus and Ipomœa pescapræ occur on the upper beach, the latter extending as far north as the beach of the island flora of Mississippi and Louisiana.

III. Vegetation of the Dunes.

1085. How dunes are formed.—Dunes are mounds or hills of sand, lying on the landward side of the beach. They are formed by the sand which is driven from the upper beach and caught in the stools or tufts of plants. They begin by the collection of small piles of sand about tufts of certain grasses; for example, marram-grass, or sea-matweed (Ammophila arenaria), the northern wheat-grass (Agropyron dasystachyum), long-leaved reed-grass (Calamovilfa brevipilis), and species of Andropogon, Elymus, etc. As the dunes grow in size other plants appear, finally an open formation of shrubs and trees is developed, and the dunes sometimes become of considerable size.

1086. Kinds of dunes.*—Dunes are described as stationary

* Cowles has made an interesting study of the dunes on the eastern shore of Lake Michigan (Ecological Relations of the Vegetation of the Sand Dunes of Lake Michigan, Bot. Gaz., 27, 1899).

›r active, or stationary ones may be further divided into embry-›nic dunes and mature dunes. A stationary dune is one that nay continue to increase in size, but does not actively move rom place to place. An active or wandering dune is one that s constantly moving from the action of the wind blowing the ;and from the landward to the leeward side. Embryonic dunes ıre, of course, young ones, and there is no distinct line to be lrawn between an embryonic and an old or mature dune. Then

Fig. 519.
Embryonic dune, shore of Lake Michigan. (After Cowles.)

one might speak of fossil dunes and rejuvenated dunes. Fossil dunes are those which have become covered for years by forest and where dune action has ceased by the disappearance or retreat of shores where wave action increases the amount of sand. Rejuvenated dunes are old dunes which have sprung into life again.

1087. Dune-forming plants.—Dune-forming plants must possess certain biological characteristics which enable them to not only live under these very severe conditions, but they must also possess the habit of growing in mats or tufts, or with the stems and branches so related or interlaced as to check the force of wind and cause the precipitation of the sand particles and afford the sand shelter. Some of the biological characters best adapted

for this purpose are: 1st, perennial habit, since the death of an annual would cease to afford shelter for the accumulated sand; 2d, rhizome propagation; by the subterranean stems the plant is enabled to spread and increase the mat and thus afford an opportunity for enlargement of the dune; 3d, ability of the stems to grow out of the sand when buried; 4th, highly developed xerophytic structures to endure the severe conditions in the sand; 5th, ability to stand at least partial root exposure where the roots on the windward side may be uncovered.

The best dune-formers as found in the Lake Michigan region, according to Cowles, are as follows:

1. Grasses with rhizome formation.
   Ammophila arundinacea. Most abundant.
   Agropyron dasystachyum (northward).
2. Grasses forming clumps.
   Elymus canadensis.
   Calamagrostis longifolia.
3. Shrubs.
   Salix adenophylla. Most abundant.
   Salix glaucophylla.
   Prunus pumila.
   Cornus stolonifera (or C. baileyi).
4. Trees.
   Populus monolifera.
   Populus balsamifera.

1088. Character of formations on dunes of different size.— Very often embryonic dunes are formed on the middle or upper beach, but these usually are temporary; sometimes those on the upper beach may migrate landward and grow to become larger dunes. In general, in age and size the dunes bear a definite relation to the shore-line, the younger and smaller ones lying toward the beach, while the older and larger ones are usually landward. There is, however, great variation in size, so that the land presents often a hilly or wavy, billowy appearance. The formations also show the same tendency from young and open ones at the beach to the older and often closed onse on the older,

higher dunes landward. There is also a corresponding gradation in the size of the vegetation comprising the formations; grasses and lower shrubs with a very open formation in the region of younger dunes; larger shrubs and often dense thickets with a few trees in the middle region of the dunes intermediate

Fig. 520.
Compact, radiate clumps of willow on sand-dunes on the outskirts of the city of Southport, England. (Photograph by the author.)

in size; while the outer landward dune region is often occupied by forests, which then are frequently continuous with the forested, sandy plane beyond.

1089. Active, or wandering, dunes.—This name has been applied to dunes which are moving, and is characteristic of many younger and growing dunes. Then also stationary dunes may change to active ones. One of the reasons why a stationary dune may become an active one is that when it increases in size plant life is limited, owing to the fact that the plants on the surface are farther from the soil moisture, since the sand does not retain water readily. In the second place, some of the trees on dunes in certain regions, the cottonwood tree for example, is of comparatively short life, and the same is true of the sand-cherry. When the plants die, therefore, the top of the dune on the windward side is blown off, because there is no vegetation to protect and hold the sand. This is the begin-

Fig. 521.
Vegetation on "sand-dune," New Jersey coast. (Photograph by Mr. Gifford Pinchot, N. J. Geological Survey.)

ning in the movement of the dune. As the top of the windward side is first blown off, this lowers the gradient on the windward side, until finally it becomes low, having about 5 per cent gradient, while the gradient on the leeward side is that which fine sand, where not disturbed by wind or wave action, takes under the influence of gravity and is about a 30 per cent gradient. These wandering dunes are often very complex; since several dunes may come together, troughs may be ploughed through the dune by the wind, forming gullies, in which case plants are uncovered. Then smaller dunes behind larger ones may be protected from the prevailing winds which come from the water. These may move in any direction by lesser winds.

1090. Effect of wandering dunes on the landward flora.— These wandering dunes often produce very great changes in the

Fig. 522.
Encroachment of a dune on old and long-established oak-dune at Dune Park. Dead oak-trees at the margin. (After Cowles.)

landward flora, since they encroach upon the plant societies, and high ones often bury the vegetation, or the mere branches of tree-tops may be projecting through. In many cases this kills the trees, and as the dune moves onward the dead trunks,

some left standing and others fallen, are sometimes spoken of as "forest graveyards" in the track of the dune. These are often found in the track of wandering dunes on the eastern shore of Lake Michigan and also on the Atlantic and Gulf coasts. Wandering dunes often encroach upon cultivated fields which are near the coast line, and thus may bury valuable arable land.

1091. Rejuvenated dunes.—As stated above under the head of kinds of dunes, a rejuvenated dune is one which has become old and inactive for a period, but becomes active again for one or more reasons, some of which have been mentioned above. Some very interesting cases of rejuvenated fossil dunes are known in New York not far from Lake Ontario.

The shore line of the great lake in glacial times which occupied the present site of Lake Ontario is still evident as a promi-

Fig. 523.

Planting grasses on wind-swept sandy coasts to prevent movement of dunes into the city, Southport, England. (Photograph by the author.)

nent ridge some fifteen to twenty miles south of the present shore. In some places in Oswego Co., N. Y., according to Professor Rowlee, are sandy elevations which were formed by dunes on the shore of this glacial lake. After the waters receded

these dunes finally became forested. The influence of man is here well shown in some cases where the forest has been cut from these fossil dunes. In some cases the land thus deforested has been pastured by sheep. The vegetation was thus so nearly removed that the wind has been able to play upon the sand again, resulting in extensive "blowouts" or "dugouts," and some of these old dunes have sprung into life again.

1092. Methods for checking the movement of dunes.—Successful efforts have been made in some cases to check the movement of dunes by planting grasses, especially those species which have been found to make good dune-formers. Among dune-formers on the Gulf coast may be mentioned the salt and creeping panicums (P. halophilum and P. repens), sea-oats (Uniola paniculata), and the seacoast marsh elder (Iva imbricata), which forms small "pedestal" dunes according to Lloyd. Along the Atlantic coast, beach plants and dune-formers are marram-grass (Ammophila arenaria), sea-oats (Uniola paniculata), sea-beach panicum (P. amarum), and the seacoast marsh elder (Iva imbricata).

CHAPTER LV.

PLANT SOCIETIES OF ROCKY AREAS, MEADOWS, AND MARSHES.

I. Vegetation of Rocky Places and New Land.

1093. Most of the convenient opportunities for the study of the vegetation of rocky places are in the later stages of the formation. We rarely have an opportunity to see the beginning and to watch the development for several years. Nevertheless rock slides occur where areas of bare rock are exposed, or falling rock at the base of a cliff may form a recent talus, or the river or stream at flood may wash the soil from a rocky area, or may pile rocks along the shore, leaving a rock area small or large exposed and entirely devoid of soil or vegetation. These places should be sought out and observed from time to time. In lieu of these opportunities one can observe rocky places where the plant formation represents different stages in its evolution. On rocky shores, whether of the precipitous bluff type, or sloping rock, smooth or creviced, of large or small boulders, the plant formations are often modified greatly by the proximity to water, in comparison with those of the interior; for example, the effect of surf action or spray. The most striking difference is perhaps seen in the tendency to a zonal arrangement of formations on the gradual slopes, whether on seashore, lake, or river, but on the irregular surface-rock shore the distribution is azonal.

1094. Open formations in rocky places.—First, rock lichens and algæ grow on the bare rock. If there are no crevices in

the rock this stage may continue for ages unless the rock is so situated that the disintegrated plant remains and the weatherings of the rock are not washed away. Umbilicaria, a dark-colored lichen, circular in form, often 10–25*cm* broad, and attached to the smooth rock by a central "umbilicus," is a good example. This is sometimes very common on smooth, perpendicular rocks by lake shores, or on boulders in moist woods or regions. Parmelia is also a common lichen clinging closely to the smooth surface of rocks. So there are here Umbilicaria formations, Parmelia formations, Theloschistes formations, etc.

1095. Lichens are among the pioneers in soil-making.—The habit which many lichens have of flourishing on the bare rocks fits them to be among the pioneers in the formation of soil in rocky regions which have recently become bared of ice or snow. The retreat of glaciers from peaks long scoured by ice, or the unloading of broken rocks along its melting edge, exposes the rocks to the weathering action of the different elements. Now the lichens lay hold on them and invest them with fantastic figures of varied color. Disintegrating rock, débris of plants and animals, join to form the virgin soil. Certain of the blue-green algæ, as well as some of the mosses, are able to gain a foothold on rocks and assist in this process of soil formation. A view of rocks thrown down by the melting and retreating edge of a glacier in Greenland is shown in fig. 525. These rocks at the time the photograph was taken had no plant life on them. At other places in the vicinity of this glacier, rocks longer uncovered by ice were being covered by plant life. One of the Greenland rock lichens is shown in fig. 524.

1095a. Succession of plants as soil is formed.—If the rock is creviced, these rudimentary soil ingredients collect in the crevices and afford a place for mosses or the smaller seed plants, especially those which form low, compact, cushion-shaped masses. Examples of crevice plants are, lichens like Cladonia, with several species; mosses like Hedwigia, Andræa, though these also grow on smooth rock; ferns like Polypodium, Dryopteris, Pellæa, some species of Asplenium; herbs like the harebell (Campanula rotundifolia),

bluets (Houstonia purpurea), alum-root (Heuchera americana), Arenaria stricta; grasses like Agrostis hiemalis, etc. Shrubs like Cornus, Spiræa, some of the cedars, etc., while trees like the white pine (Pinus strobus), also Pinus divaricatus, oaks (Quer-

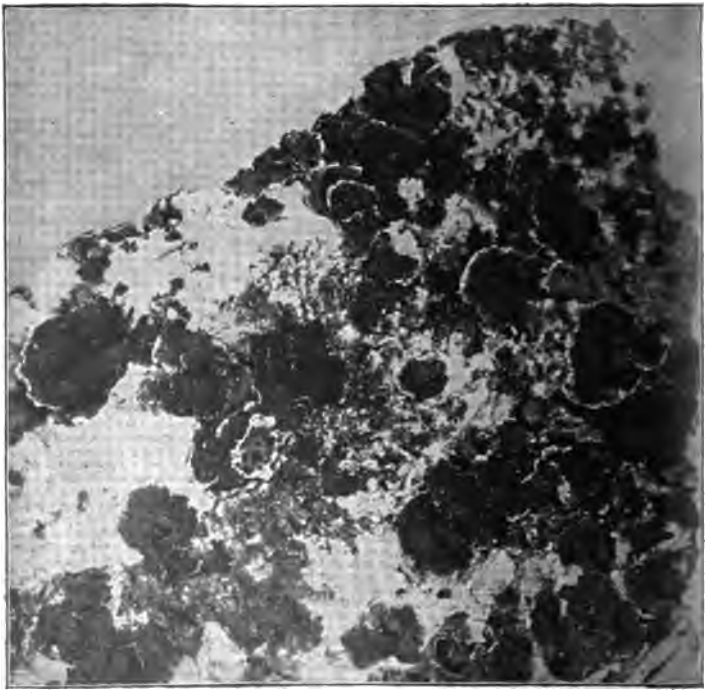


Fig. 524.
Rock lichen (umbilicaria) from Greenland.

cus macrocarpa), ash (Fraxnus americana),, and trembling poplar (Populus tremuloides) occur.

1096. Transition of open formations into close ones.—This vegetation together with greater accumulations of fine rock ingredients provides soil in the crevices where plants with greater stem development may gain a foothold in the crevices. These

plants stand farther from the substratum and gain an advantage in light relation above the earlier ones. In case the creviced rock is where soil may be washed over the rock occasionally in high flood, an older type of plant formation may begin at once, since

Fig. 525.
Edge of glacier in Greenland, showing freshly deposited rocks. (From Prof. R. S. Tarr.)

the crevices are apt to be filled with soil left by the flood. Eventually the accumulation of soil may be so great as to encourage a close or climatic formation.

1097. Retention of made soil.—In the struggle of plants for existence, there are a number of species which stand ready to

rush in where new opportunities present themselves by changed conditions or by newly made soil. The permanent drainage of ponds or marshes brings changed conditions, and the flora there undergoes remarkable transformations. The deposits of the washings of streams in protected places along the shores, or at their mouths, where deltas or lateral plateaus are made by the accumulations of soil scoured off the banks of the stream, or

Fig. 526.
Sycamores, grasses, and weeds, starting in crevices on a rock bed, New York.

washed off the fields during rains, make new ground. With such banks of newly made ground are deposited seeds carried along with the soil, or dropped there by the wind, by birds, or other agencies of seed distribution.

Plants vary greatly in their capacity to occupy and hold new territory and to invade occupied territory and displace the inhabitants. The first plants to get a foothold are not always the ones to endure longest, and a royal struggle takes place during years

for supremacy. The most aggressive species win out in the end. But it must be understood that with this aggressiveness there must also be adaptability to the conditions of environment, for a plant which might succeed under one set of conditions might fail ignominiously under another set of conditions. So, too, certain plants may be especially adapted to a certain set of conditions, but may have the effect of so changing the conditions by building up soil or the accumulation of humus that other aggressive species may now enter and dispossess them. In this way the plant formations build one upon another, gradually approaching the climax type, which remains permanent so long as conditions are unchanged, but the climax type itself often goes down in the event of the action of great physiographic, climatic, physical changes, or biological factors.

In the past little attention has been given to the development or evolution of the climax vegetation types from the embryonic ones. Treub, in 1888, studied the rehabilitation of plants of the volcano Krakatau three years after the mountain was covered with glowing lava (Bimstein) and volcanic ash. The dry rock and ash was first covered with microscopic blue-green algæ (Cyanophyceæ), which formed a soil for ferns of which in three years there were eleven species, besides scattered seed-plants. Schimper studied the vegetation of the volcano Guntur in West Java, which at the time of the eruption in 1843 was covered with glowing volcanic matter. The vegetation was still quite open and in places thin. There were no trees, while shrubs and herbs were present as well as numerous ferns, but not forming the chief mass of vegetation as at Krakatau. A remarkable thing was the fact that many species which in the forests were epiphytes, growing near the forest top where they could obtain light, were here growing on the rocks, where in the open formation light was abundant, as many ferns, orchids, and shrubs like Rhodendron javanicum, and Nepenthes with its pitchers containing water and numerous insects. Flauhault and Combres have traced the growth of the vegetation in the sandy and dune lowlands of Camargue in the delta of the Rhine, from the naked ground formed in floods, through the open, and later to the close formations (1894). Vegetation established here and there on the beach during the winter is swept by the ocean storms and torn away. But occasionally tufts hold their ground over winter. These increase, catch humus, afford a foothold for other salt-loving plants; a small dune is formed; this grows; the rhizomes of grasses and shrubs binding the soil and holding the life of the plant through the winter period. As the dune becomes larger it

moves above and beyond the wave action of the salt water. Rains change the salt moisture from salt to fresh and the vegetation changes from halophytes to psammophytes, the latter being grasses adapted to sandy soil with fresh-water infiltration. By wind action sand is carried farther from the shore, and dunes of varying size and age are formed parallel with the shore. The younger ones near the shore have the open formations, while farther inland the older ones begin to take on a closed formation with trees and shrubs more abundant, a sign that the climax type is being reached. MacMillan in 1898 has used the same method with excellent results in his study of the distribution of plants on the shores of the Lake of the Woods in northern Minnesota. Later Cowles (1898) has applied the same principle in the study of the Physiographic Ecology of Chicago, and in his studies of the sand-dunes of Lake Michigan. Whitford (1898), Genetic Development of the Forests of Northern Michigan; Kearney, Vegetation of the Dismal Swamp; Ganong (1903), The Vegetation of the Bay of Fundy Salt and Diked Marshes; Fink (1903), Some Talus Cladonia Formations, and others.

II. Vegetation of Swamps and Moors.

1098. Mud swamp or reed societies.—The flora of some soil shores is very closely related to that of the mud swamp. The ground is rich in nitrogenous plant-food from well-decayed vegetation matter mixed with the soil. The characteristic plants are bullrushes, reed-grasses, cattail-flag, sparganium, sedges, arrow-leaf, and often pondweeds and pond-lilies. These plants grow in rather shallow water of varying depth, and thus where the ground is sloping often show the zonal arrangement with very distinct formations (as Typha formation). The reeds and bullrushes usually stand out with the greater part of the plant above the water, and while they are by some called hygrophytes, or hydrophytes, the aerial parts are of such a structure as will retard transpiration. This would seem necessary since so large a part of the plant is exposed to sun and wind, while the roots are immersed in water and absorption is thus lessened. Where they stand in this relation to water they are often called semiaquatic plants. The water-lilies, pondweeds, arrow-leaf, etc., are true hydrophytes. With the accumulation of vegetation year after year the water becomes shallower in the mud-swamp, until the

ground is built up to water-level, when it passes into the type of the meadow swamp.

1099. Meadow-swamp societies, or meadows.—These represent a progressed stage of the mud or reed swamp. Grasses and sedges suited to growing in wet soil or in swales follow the reed-grass and scirpus, forming meadow-like expanses. Here and there one or more species of grass or other herb would dominate and make the formation, as Cyperus formation, Carex formation, or the true grasses, according to the dominant species. A luxuriant vegetation is usually formed because the soil is black and rich with nitrogenous plant-food, and the low situation of the ground assures an abundance of ground-water. These are the true meadows, though the name is given popularly to any meadow-like expanse on higher ground where grasses are the dominant vegetation forms, whether in waste places or cultivated areas. See also meadow-moors in the following paragraph.

1100. Peat-moor societies, or bogs (*also called muskeag*).—The ground of the peat-moor or peat-bog is largely composed of peat characterized by an abundance of vegetable matter. In the moor only partial decay of vegetation takes place. This is due to an abundance of water, which accounts for the small amount of oxygen, the absence of the kinds of bacteria and fungi which reduce vegetation to humus and finally to plant-food. There is produced then an abundance of humus acid in the form of humates. Two kinds of peat-moors are recognized by some, characterized by the presence or absence of lime. The "high" moors have an abundance of free humus, but lime is lacking, while in the so-called meadow-moors, which do not have such a thick ground formation, the humus acid is combined with lime. Both of these kinds of moors are poor in mineral substances because, being built up of decaying vegetation in the water, the decay is only partial, "ground" is built up rapidly upon the bottom of the pond, and rock-soil constituents are largely excluded. They are rich in nitrogenous matter, but this is combined with humus in the form of humified albuminous bodies. It is thus not readily available for plant-food. This, together

with the fact that the humus acid present in the moor retards absorption, gives a very characteristic aspect to the vegetation of the moors. The vegetation is more or less xerophytic. While some plants which grow on higher ground are found in moors, still there are many plants which are characteristic of the moors. Some of these plants are found in both the high moor and meadow-moor, but there are a few which are characteristic of each kind, so that the meadow-moor contains many species which are not found in the high moor.

Fig. 527.
Two fruiting plants of sphagnum. (From Kerner and Oliver.)

The meadow-moors have grasses or sedges as the dominant vegetation, so that there are "meadows," or meadow-like expanses of grasses. These would be classed technically with meadows, but differ from the other types, where there is more true soil and vegetation thoroughly decayed.

The high moors have been built up principally by growth of the peat-moss, or sphagnum. The spongy character of the cushions of sphagnum enables it to lift water up from below so that the lower parts are partially decayed and yet the upper parts are abundantly supplied with moisture. The structure of the plant is especially favorable for lifting up water. The main axis bears lateral branches nearly at right angles, but with a graceful downward sweep at the extremity. These primary lateral branches bear secondary branches, which arise, usually several, from near the point of attachment to the main axis

They hang downward, overlap on those below, and completely cover the main axis or stem. The leaves of sphagnum are peculiarly adapted for the purpose of taking up quantities of water. Not all the cells of the leaf are green, but alternate rows of cells become broadened, lose their chlorophyll, and their protoplasm collapses on the inner faces of the cell-walls in such a way as to form thickened lines, giving a peculiar sculpturing effect to them. Perforations also take place in the walls. These empty cells absorb large quantities of water, and by capillarity it is lifted on from one cell to another. These pendant branches, then, which envelop the sphagnum stem, lift water up from the moist substratum to supply the leaves and growing parts of the plant which are at the upper extremity. Year by year the extension of the sphagnum increases slowly upward by growth of the ends of the individual plants, while the older portions below die off, partly disintegrate, and pass over into the increasing solidity and bulk of the peat. It thus happens sometimes that the centers of such basins or moors are more elevated than the margins, because here a greater amount of water exists in the depths which is pumped up for use by the plants themselves. This is why such a formation is called a "high" moor.

Among the plants found in moors are the leather-leaf (Cassandra), Andromeda polifolia, the cranberry, Labrador tea, etc. These plants have rather small, thick, and firm leaves with a thick cuticle and the under surface in some species provided with scales or hairs to lessen the amount of transpiration. Andromeda polifolia has narrow leaves with a thick cuticle and the edges are inrolled. The Labrador tea has small elliptical leaves with a thick cuticle and the under surface covered with a dense mat of hairs. The moors are often found where were formerly small shallow ponds, or are found on the shores of larger bodies of water. The rapid accumulation of vegetable matter where it only partially decays, builds up the ground floor to such an extent as to completely fill smaller ponds or lakes which are not very deep. In the high moor this ground is built up more rapidly than in the meadow-moor, and eventually, when

the pond is filled, the ground formation in the center becomes more elevated than toward the margin. Transeau (1903) has shown in an interesting way how these plant societies of peat-moors are related to the arctic tundra. The evidence seems to show, as earlier students have also pointed out, that during the glacial period these arctic plants moved southward in advance of the great ice-sheet. When the glacier retreated to the north many of these plants were left behind. In situations like the present moors, where the climatic type of vegetation could not take possession of the ground because of soil peculiarities, these arctic plants have retained possession; the very soil conditions here which prevent the growth of the forest favor the growth of these plants. It has long been known that a number of the heaths and other shrubs growing in these moors were very similar to and in a few cases identical with certain species growing in the cold wastes of arctic regions. For example, the moss plant (Cassiope hypnoides), the four-angled cassiope (Cassiope tetragona), and others extend from the Northern States to arctic America.

1101. Insectivorous plants on moors.—Most plants growing in moors have difficulty in obtaining food because of the small amount of mineral substances, the unavailable form of much of the nitrogen, and the interference with absorption due to lack of oxygen and the presence of humus acid. Some moor plants, however, are assisted in obtaining food because of their carnivorous habit. These are the insectivorous plants like the sundews (Drosera), the pitcher plant (Sarracenia purpurea), the butterwort, or bog violet (Pinguicula vulgaris), the horned bladderwort (Utricularia cornuta), etc. In the sundews there are viscid glandular hairs (fig. 127) on which flies get stuck. These hairs are sensitive, they bend inward, bearing the fly against the leaf so that it folds over it, and certain juices from the leaf digest the insect. In the butterwort the flies are stuck to the surface of the sticky leaf. In the bladderwort, many species of which grow in water, there are bladder-like leaves with a trap-door at the opening, so that insects can easily swim

in but cannot get out. The Venus's fly-trap (Dionæa muscipula, fig. 126) on sandy coastal lowlands of North Carolina is one of the most remarkable of the insectivorous plants. When insects alight on the leaf and irritate the hairs on the surface the leaf closes suddenly and the stout hairs on the edges fit in between one another like the teeth of a steel trap and prevent the escape of the insect, while the surfaces of the leaf are gradually pressed tightly against it, and fluids exuded by the leaf digest the insect.

1102. A plant atoll.—In the morainic regions of central New York there are some interesting and striking examples of the effects of plants on the topography of small and shallow basins. These formations sometimes take the shape of "atolls," though plants, and not corals, are the chief agencies in their gradual evolution. Fig. 484 is from a photograph of one of these plant atolls about fifteen miles from Ithaca, N. Y., along the line of the E. C. & N. R. R., near a former flag-station known as Chicago. The basin here shown is surrounded by three hills, and is formed by the union of their bases, thus forming a pond with no outlet.

Topography of the atoll-moor.—The entire basin was once a large pond, which has become nearly filled by the growth of a vegetation characteristic of such regions. Now only a small, nearly circular, central pond remains, while entirely around the edge of the earlier basin is a ditch, in many places with from 30–60 *cm* of water. There is a broad zone of land then lying between the central pond and the marginal ditch. Just inside of the ring formed by the ditch is an elevated ring extending all around, which is higher than any other part of the atoll. On a portion of this ring grow certain grasses and carices. The soil for some depth shows a wet peat made up of decaying grasses, carices, and much peat-moss (sphagnum). In some places one element seems to predominate, and in other cases another element. On some portions of the outer ring are shrubs one to three meters in height, and occasionally small trees have gained a foothold.

Next inside of this belt is a broad, level zone, with Carex filiformis, other carices, grasses, with a few dicotyledons. Inter-

Fig. 598.

Atoll-moor, showing central pond, elevated ring, and ditch at original shore-line. Near Ithaca. (From photograph by the author.)

mingled are various mosses and much sphagnum. The soil formation underneath contains remains of carices, grasses, and sphagnum. This intermediate zone is not a homogeneous one. At certain places are extensive areas in which Carex filiformis predominates, while in another place another carex, or grasses, predominate.

A floating inner zone.—But the innermost zone, that which borders on the water, is in a large measure made up of the leather-leaf shrub, cassandra, and is quite homogeneous. The dense zone of this shrub gives the elevated appearance to the atoll immediately around the central pond, and the cassandra is nearly one meter in height, the "ground" being but little above the level of the water. As one approaches this zone the ground yields, and by swinging up and down, waves pass over a considerble area. From this we know that underneath the mat of living and recent vegetation there is water, or very thin mud, so that a portion of this zone is "floating."

The inner, or cassandra, zone is more unstable, that is, it is all "afloat," though firmly anchored to the intermediate zone. The roots of the shrubs interlace throughout the zone, firmly anchoring all parts together, so that the wind cannot break it up. Between the tufts of cassandra are often numerous open places, so that the water or thin mud on which the zone floats reaches the surface, and one must exercise care in walking to prevent a disagreeable plunge. No resistance is offered to a pole two to three meters long in thrusting it down these holes. Grasses, carices, mosses, sphagnum, and occasionally moor-loving dicotyledons occur, anchored for the most part about the roots of the cassandra. Standing at the inner margin of the cassandra zone, one can see the mud, resembling a black ooze, formed of the broken plant-remains, which have floated out from the bottom of the older formations. In some places this lies very near the surface, and then certain aquatic plants, like Bidens and others, find a footing. Upon this black ooze the formation can continue to encroach upon the central pond. Agitated by the wind, more and more of the ooze passes outward, so that in time there is a

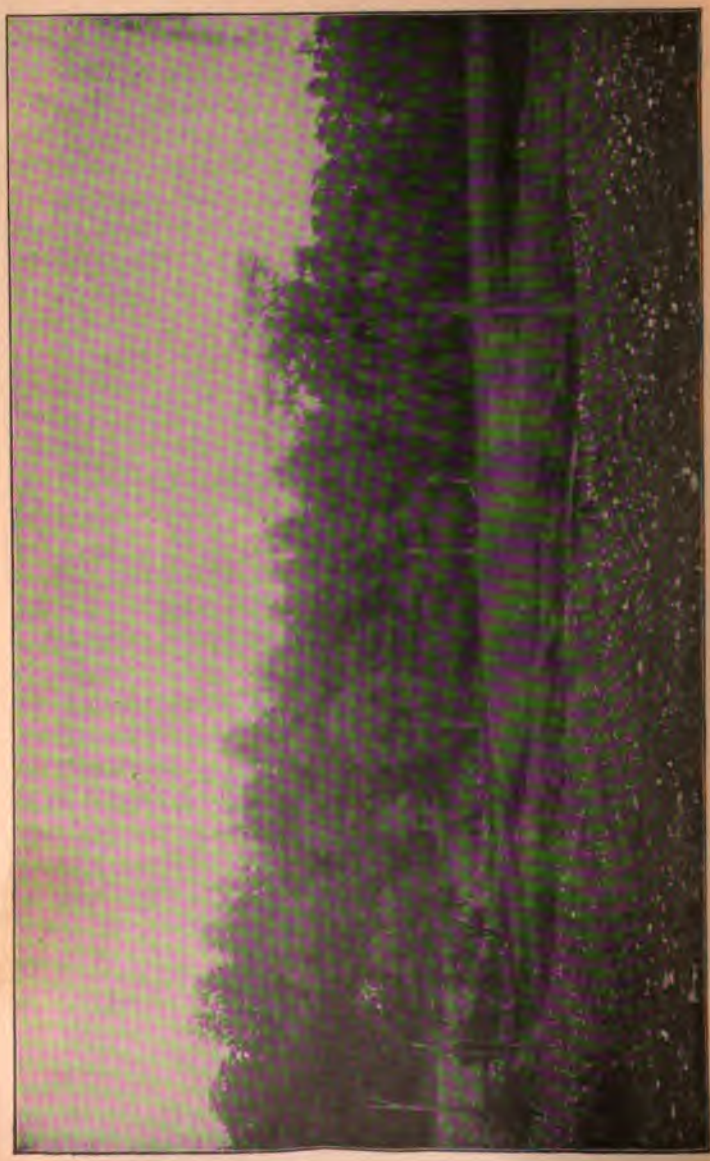


Fig. 319.

One side of a hill-moor, showing two elevated areas of marks land from marginal ditch to central pond. (Photograph by the author.)

likelihood that the pond will cease to exist, yielding, as it has in other places, the right of possession to the encroaching vegetation.

How was the atoll formed?—In the early formation of the atoll it is possible that certain of the water-loving carices and grasses began to grow some distance (three or four meters) from the shore, where the water was of a depth suited to their habit. The stools of these plants gradually came nearer the surface of the water. As they approach the surface other plants, not so strong-rooted, like mosses, sphagnum, etc., find anchorage, and are also protected to some extent from the direct rays of sunlight. Partial disintegration of the dead plant parts, which, mingling with the soil, gradually fills on the inside of the zone, so that the depth of the water there becomes less. Now the zone of the carices can be extended inward.

The continued growth of the sphagnum and the dying away of the lower part of the plant add to the bulk of the plant-remains in the zone, and finally quite a firm ground is formed, shutting off the shallow water near the shore from the deeper water of the pond. As time goes on other plants enter and complicate the formation, and even make new ones, as when the cassandra takes possession.

The original pond here was rather oblong, and one end possibly much shallower than the other, so that it filled in much more rapidly, leaving the central pond at the east end. Over a portion of the west end there is an extensive cassandra formation, with some ledum (Labrador tea), but separated from the circular cassandra zone by an intermediate zone. In this end-cassandra formation other shrubs, and white pines five to fifteen years old, are gaining a foothold, and in a quarter of a century or more, if left undisturbed, one may expect considerable changes in the flora of this atoll.

The ditch on the margin of the atoll-moor was probably formed because of the shade offered by the forest on the banks. On the side where the original forest still stands the ditch is deeper, and where it is heavily shaded no vegetation is present close to

the bank except some algæ and liverworts. On the sides where the forest has been cleared off swale-grasses are growing in the ditch or marginal depression and ground is being slowly built up.

1103. Heaths.—Heaths or heath-moors are plant societies where heaths are the dominant vegetation. Examples of heaths are huckleberries and bearberries, cranberries (Vaccinium species), but especially members of the Ericaceæ, like wild rosemary (Andromeda), dwarf cassandra (Chamædaphne = Cassandra), heather (Calluna vulgaris), etc. These usually occur in sphagnum-moors (see sphagnum-moors), but sometimes heath

Fig. 530.

Heather formation on sand in crevices of rock. Heather (Calluna vulgaris) in the foreground and in rock crevices on the left. At the right a few dwarfed, stunted trees of Pinus sylvestris bent to one side by wind. On rocky hills, coast of Sweden, Botanic Garden, Gothenburg. (Photograph by the author.)

formations are on sandy ground, which is more elevated and dry, especially the heather (Calluna vulgaris). The heather forms extensive heaths in northwestern Europe either in moors or on dry, sandy ground. It also occurs in northeastern North America, but is rather local.

1103a. Spruce and tamarack swamps.—The black spruce and the larch or tamarack often encroach on the peat-moors, heaths, or muskeags, and make distinct formations. The trees in this

situation are usually of slow growth. The under vegetation consists of shrubs, herbs, and mosses like those on the moors

Fig. 531.
Dying black spruce in moor. Note the abundance of cotton-grass (Eriophorum). (Photograph by the author.)

described in paragraphs 1090–1093. In open places, or in moors where the spruce is dying because of fires or floods, the cotton-grass is often abundant, as shown in fig. 531. This grass also occurs on other moors.

1104. Cane-swamp societies.—These are frequent in the Southern States in low ground along streams, and are formed by a dense growth of the cane, Arundinaria.

1105. Salt-marsh societies.—These are formed along the salt shores of the ocean or of salt lakes, where the gradient of the shore is low and the soil is nitrophytic. The water is brackish and varies in its salt content according to the relation of the marsh to the sea and to the run-off from the land. The seed plants are rooted in the soil, which is either very wet with the brackish water, or entirely submerged, and the plants also more

or less submerged. With many of these plants the upper parts are above the water. Because of the large salt content in the water the plants absorb it with difficulty. The aerial parts then are provided with leaves and stems which retard transpiration. They are thus xerophytic in structure and habit, but are often called halophytes because of their adaptation to a large salt content in the salt water. A similar flora is found around salt springs. For example, the maritime ruppia (Ruppia maritima), a plant found in brackish water along the seacoast, occurs in the water near salt springs in Onondaga County, New York, and also in alkaline basins in the West, while Salicornia, etc., occur on the ground in the same regions. Characteristic salt marshes are the meadows with marsh-grasses. The mangrove

Fig. 532.
Plants marching into the sea. They have advanced from the trees at the left in about two hundred years. Meadow in salt marsh.

swamp is also a characteristic one, but this is treated of in forest societies. Ganong in an important paper has shown how much

of the area covered by the salt marshes of the Bay of Fundy has been converted into arable land, especially for the growth of hay. The farmers in that section "dyke" the marshes to prevent their being flooded during high tide. Many of the true salt-marsh plant formations, as well as the conditions of environment, are discussed. One of the most characteristic halophytes of the salt marshes here is the sedge spartina (S. stricta glabra). It grows on the shore down to the water's edge along the open ocean, and here the plants are low and stunted, since they are subject to the strong salt water during tide. It is also one of the characteristic plants forming meadows in the brackish waters, and here it is more luxuriant. It possesses true xerophytic structures, propagates chiefly by subterranean shoots, and the stems and leaves have ample air-spaces. The abundance of air in the plant enables it to endure prolonged and frequent inundation by the tides. Ganong has found by experiment that the root-hairs of a number of seedlings of these salt-marsh plants resist plasmolysis when immersed in quite strong saline solutions, and this probably explains why it is these plants are able to grow in soil and water of such salt concentration.

1106. Shores of marl ponds.—On the shores of marl ponds the soil is calcareous, i.e., it contains large quantities of lime in the form of carbonate of lime, mixed with sand and clay in variable proportions in different localities. These shores often furnish a characteristic vegetation which is usually xerophytic. On the shores of marl ponds in New York the shrubby cinquefoil (Potentilla fruticosa = Dasiphora fruticosa) is often one of the common formations. The usual habitat for this species is in swamps and rocky places from Labrador to Greenland and Alaska. (See marl ponds in Chapter LVI.)

CHAPTER LVI.

AQUATIC PLANT SOCIETIES.

I. General Considerations.

In this chapter are treated the vegetation forms which are for the most part submerged. Some float on the water with their upper surface exposed. In others the leaves float on the water, while in still others the leaves may be lifted considerably above the surface. They differ from the plants of swamp societies in that the plants of the latter have all or a large part of their body out of the water, and are usually supplied with mechanical tissue for self-support. (These semi-immersed plants are sometimes called semi-aquatics.)

1107. General characters of aquatic plants (see also Chapter XLVII, Hydrophytic structures).—A typical aquatic plant has at best only a slight development of mechanical tissue; it is supported by the water; it is provided with air by large air-spaces throughout the tissue; all or nearly all parts being surrounded by water, absorption takes place directly and there is little or no development of root-hairs, and only a feeble development of fibrovascular tissue; where roots are developed they serve chiefly as holdfasts. Water-plant societies grade into swamp societies and these into the vegetation of soil shores. In fact all three types may be present in the same pond or lake or shore, shallow water, or deep-water vegetation.

1108. Two general divisions of aquatic plants.—In studying plant societies growing in water it is convenient to divide them

into two groups which correspond with the divisions: *hydrophytes*, which grow in fresh-water streams, lakes, ponds, etc.; and *halophytes*, or those which grow in the ocean or in salt lakes. The fresh-water plants are sometimes called *limnetic*, and the marine forms *pelagic*. In both the limnetic and pelagic floras there are plants which are fixed to some place of support (to the rocks, lithophytes, as in case of pelagic forms; to the soil, as in case of most limnetic forms; while algæ, etc., attached to other plants are epiphytes), while others are free-floating or swimming.*

1109. Different regions of light in deep water.—Aquatic plants are distributed at different depths in the water, and it is surprising the depth at which some can live. It is obvious that plants located at different depths will have different light relations, those near the surface being well lighted, while those lower down will receive light of diminished intensity. Light is the controlling factor, and three regions are recognized. 1st. *The bright-light region*, or *photic region*, in which the light intensity is favorable for the normal development of the larger plants, (macrophytes). It is the region also of most of the microphytes which have photosynthesis, especially the green algæ. 2d. *The dimly-lighted region*, or *dysphotic region*, where most of the macrophytes reach only a stunted growth or fail, and where a

* Schimper uses the term *Benthos* or benthonic (βενθος=depths) for those forms which are fixed. *Plankton* is the term applied to the free-swimming or floating forms, but perhaps its best expression is now for the swimming microscopic plant and animal forms of deep water. Plankton was first used to signify pelagic animals. The best examples of plant plankton are found in the Protococcoideæ, floating and swimming green algæ, as Volvox, Pandorina, Eudorina, Chlamydomonas, etc., the desmids, the blue-green algæ, the Peridineæ, and the diatoms especially. The diatoms have a siliceous external skeleton. They occur in great numbers in fresh water, but in vastly greater numbers in the ocean. In geologic times they were so abundant for long periods that their skeletons have built up great rock formations. Hemiplankton is a term applied to those plants floating and swimming in the shallow water of the coast or in the shallow waters of inland lakes and ponds, where they are mixed with benthonic forms.

few photosynthetic microphytes, especially diatoms, grow. 3d. *The dark region*, or *aphotic region*, only occupied by those

Fig. 533*a*.
Macrophytes in the upper zone of the photic region. Ascophyllum and Fucus at low tide, Hunter's Island, New York City. (Photograph by M. A. Howe.)

organisms not capable of photosynthesis (certain bacteria for example).*

1110. Concentration of salt water.—The degree of concentration of salt solutions in water affects the distribution of plants. The concentration of salt water varies in the different inland salt lakes and seas because of the varying rapidity of evaporation and the different proportions of fresh water draining into them. The concentration of the salt water of inland seas is different from that of the ocean, and here it usually diminishes from the open sea toward the coast. The greatest salt content, according to Schimper, is found in the Red Sea † (4.3 per cent), in consequence of rapid evaporation and the small amount of fresh water flowing into it, while in the Baltic Sea it is as low as 1 per cent. In the ocean the content of mineral matter is about 3.5 per cent, of common salt about 2.6 per cent, and it is greater in tropical

* In the Gulf of Naples living bacteria have been found at a depth of 250–1100*m* (=800–3500 ft.).

† The color of the Red Sea is due to the red schimmer given it by the swimming alga Trichodesmium erythræum, one of the Cyanophyceæ.

than in arctic or antarctic regions. At the mouth of rivers and streams, in salt marshes, and in some inland salt seas which have a large influx of fresh water, it is "brackish," i.e., slightly saline.

1110a. Movement of water also affects the form and character of aquatic plants. In quiet fresh water the plants are different from those in streams. Ebb and flow of tide show their effect on pelagic forms. The physical condition of the substratum, whether rock or soil, affects the benthonic vegetation. Aside from the effect of salt water, the flora of fresh waters is influenced accordingly as it is rich or poor in calcium carbonate.

1110b. Temperature exercises considerable influence on the distribution of water plants, but is not so important a factor as it is on land because it is more equable. Most of the perennial pelagic algæ show no period of rest; usually the summer is the growing period and winter the fruiting period, though there are a number of exceptions to this. A greater difference is manifest in the inland lakes and ponds, especially in the cool temperate regions, where the formation of ice interrupts the growth, the perennial benthonic forms passing through a period of rest for their shoots, and the annuals and plankton passing the period through seeds, spores, hormogones, akinetes, or resistant vegetation parts. Many bacteria and some algæ will live enclosed in ice for considerable periods. Certain benthonic algæ (Lemanea) in fresh-water streams pass both the growing and reproductive period in winter often under ice, and rest during the summer period. Warm currents exercise an influence on the distribution of pelagic algæ, but not so markedly as they do on land plants.

1111. Inland salt ponds and lakes.—Since, in a number of the inland salt lakes and seas, the percentage of salt is very high, plant life is more restricted than in the ocean, and in some cases is prohibited. But at the intake of fresh-water streams the salinity would be reduced and permit the growth of certain halophytes. The vegetation of the saline waters of the Great Salt Lake in Utah has not been carefully studied with reference

to environment, and yet we know something of the halophytic vegetation of some of the alkaline waters and of the soil shores of the lakes and ponds in the arid regions. See alkaline marshes and Bad Lands in Chapter L. The vegetation in the vicinity of the Great Salt Lake is similar to that mentioned here.

1112. Marl ponds.—The water in marl ponds contains a large percentage of carbonate of lime. Plant life is, therefore, somewhat restricted. Certain species of Chara (one of the algæ), however, are often very abundant in the waters of marl ponds, and the plants are very brittle because of the large amount of carbonate of lime in their tissues. (See shores of marl ponds in Chapter LV.)

1113. Vegetation of hot springs.—The vegetation of hot springs is remarkable for the high temperatures at which certain bacteria and blue-green algæ can grow. In America the most notable instance is the vegetation of the hot springs and geysers in Yellowstone National Park. Certain filamentous bacteria grow in hot water, the temperature reaching as high as 70°–82° C., or rarely as high as 89° C. In water slightly cooler, 65°–68° C., or even scantily at 75°–77° C., species of the Cyanophyceæ, like Phormidium, occur, and in still cooler waters of the hot springs are found Anabæna, Glœocapsa, etc. Some of these waters are rich in carbonate of lime, which some of these plants deposit, forming curious and often fantastic figures in the basins.

II. Fresh-water, or Limnetic, Plant Societies.

1114. Pond or inland-lake societies.—These should be observed in connection with swamp societies and the flora of soil shores, since the semi-aquatic plants, like the bulrushes, cattail-flags, arrow-leaf, etc., growing in the shallow water of the pond or lake margin, are the transition forms from the lowland or swamp flora to the truly aquatic plants. In general several zones can be recognized from the shore lakeward (see Chapter LV). The first is a *littoral* zone, and includes the semi-aquatics like those mentioned above, and this is connected with the

strand flora by different plants, according to the soil conditions, locality, and other conditions of environment or factors of distribution (herbs, grasses, etc.). The second zone, *mid* zone, is characterized for the most part by plants with floating leaves and slender petioles or stems, like the water-lilies, the floating potamogeton (P. natans), the water-fern (Marsilea). It is interesting to note from year to year, as the water may be at different depths, that the perennial plants fixed to the bottom have short or long petioles according as the water is shallow or deep. Some plants in this zone are entirely immersed, like the quillwort. The latter sometimes in small ponds makes pure formations. In fact any of the zones may be pure or mixed, one or several facies making a formation, as in the case of land plants. The third is a *submerged* zone and has plants of the true pondweed type. These occupy deeper water, and while nearly always submerged, their leaves are brought near the surface for light by the elongation of their stems. These should be contrasted with such a plant as the quillwort, which does not have this power of adaptation. Some of the pondweeds grow where the water is up to 6*m* (20 ft.) or more deep.

1114a. The three zones mentioned above are to be taken in a broad sense, and relate to: 1st, littoral zone, the semi-aquatics; 2d, mid zone, the forms with floating leaves; and 3d, submerged zone, the completely submerged plants. In regular bowl-shaped ponds or lakes there might be, and usually are, several plant formations arranged zonally within each of the zones mentioned above. To take, for example, the formations illustrated in fig. 534. In the littoral zone of semi-aquatics there are three zonal formations: typha (1), the bulrushes (2), and arrow-leaf (3). In the mid zone (adjacent to this) the yellow water-lily, and potamogetons with floating leaves (4). In the submerged zone are two zonal formations, pond-lilies (5), and bass-weed=Chara (6). According to Magnin, in the small lakes of Jura there are usually six zones, and these correspond as follows to the three zones mentioned above: 1st, littoral zone of semi-aquatics, zone of sedges (1), zone of reed-grasses (2),

zone of bulrushes (3); 2d, mid zone, zone of pond-lilies (4); 3d, submerged zone, zone of pondweeds (5), zone of bass-weed, Chara (6). We see then that in different localities these three different zones may be represented by different species, but the vegetation types in the different zones are the same.

1114b. The free-floating forms, like the duckweed, riccias, Salvinia, etc., are found on the surface in the first and second zones, floating between the stems and leaves. These are buoyed up by large intercellular air-spaces. Here occur also floating mats of algæ, like Spirogyra, Vaucheria, Œdogonium, etc., which are buoyed up by the bubbles of gas entangled in the meshes of the mat, or algælike Cladophora, which are attached to the reeds or bulrushes, or Coleochæte, which forms sessile disks on the same supports. Then there are the numerous free-swimming green algæ floating in the meshes of thread-like alga mats, or swimming on the surface, or resting on larger plants, or on the bottom in shallow places, as well as numerous blue-green algæ, diatoms, bacteria, and the water-mold fungi.

1115. River, or fluviál, plant societies.—The plants which grow in the running water of streams constitute a rather distinct type from those in quiet water. Because of the continued movement of the water, sometimes rapid or violent, the plants are attached to the rock or rooted well in the ground, and have flexile stems, with only slight leaf development, or the leaf may not be well differentiated from the stem. This type of stem is suited to the waving movements produced by the flowing water. The river-weed (Podostemon) is a good example of one of the seed-plants which has become so changed in its adaptation to an aquatic life that it strongly resembles certain algæ; the mosses are represented by Fontinalis, and the algæ by Cladophora and Lemanea.

Where the water is shallow or quiet, as in pools or ponds having an open connection with the streams, the societies are of the pool or pond type. Semi-aquatics (bulrushes, reed-grasses, arrow-leaves, pickerel-weeds, etc.) often develop along the shore of streams or in shallow water in midstreams, where

they often catch débris, and eventually fix a soil upon which shore vegetation, then land herbs and shrubs, and finally trees grow.

1116. Structural types of limnetic plants.—There are certain types of plant form and structure in relation to the water environment recognized. These are as follows:

1. *The quillwort type.*—Plants submerged, rooted to the soil, with rosette habit and mostly cylindrical terete leaves. This type is represented by the Isoetes, or quillwort formation, the Pilularia formation, water-lobelia formation, etc.

2. *The water-lily type.*—Plants floating with leaves and long flexile petioles or stems arising from creeping or subterranean perennial rootstocks. Examples: white water-lily formation (Castalia odorata = Nymphæa odorata), yellow water-lily formation (Nymphæa advena = Nuphar advena), water-fern formation (Marsilia formation), floating pondweed formation (Potamogeton natans formation), etc.

3. *The pondweed type.*—Plants entirely submerged, rooting to the soil, with long slender floating stems. Examples: most of the pondweeds (Pondweed formations), Zannichellia formation, Naias formation, Heteranthera formation, Myriophyllum formation, etc.

4. *The duckweed type.*—Free floating plants with short stems, or "fronds." Examples: duckweed or duckmeat (Lemna) formation, Riccia formation (Riccia natans, fluitans, etc.), Salvinia formation, Azolla formation, etc.

5. *The river-weed, or fluvial, type.*—Plants fastened to stones in streams, entirely submerged, stems slender, flexible, frond-like, leaves not differentiated. Examples: river-weed (Podostemon) formation, Fontinalis (fluvial mosses) formation. Among the algæ fluvial forms like Cladophora, Lemanea, etc., belong here.

III. Marine, or Pelagic, Plant Societies.

1117. By far the larger number of the fixed, or benthonic, marine plants are lithophytes (attached to rocks), and the larger number of these are algæ. The larger ones are attached by

disk-like, or lobed, holdfasts, while the diatoms are attached by stems of gelatine. A large number of the smaller ones are epiphytes, and there are many semiparasites also among the algæ, as well as some fungus parasites. Very few marine plants are attached to the mud or sandy bottoms. These places correspond to deserts in the paucity of their flora. The few plants found here (Caulerpa, etc.) are attached by root-like holdfasts, or in the shallow places meadows of sea-grass (Zostera) are found. The larger algæ are almost exclusively confined to the photic region (extends $30m$–$40m = 100$–125 feet deep), while seed-plants are exceptional.

1118. The photic, or bright light, region is divided into two broad zones; the upper one is periodically exposed by the movement of the tide and lies between limits of ebb and flow. The lower zone of the photic region lies below ebb-tide.

1. *The upper photic zone.*—This is again divided into two strata, the lower one being the most favorable for development, since the members are only partially exposed at low tide. In the upper stratum the conditions are austere, since the complete and long uncovering exposes the plants to the danger of drying out. The plants are generally somewhat stunted in growth, stout, with a thick epidermis, and are sparingly branched, and they are exclusively algæ; example, Fucus vesiculosus.

2. *The lower photic zone.*—To this zone belong all the marine seed-plants and the great mass of algal vegetation. This zone is also divided into strata, dependent, however, upon the diminishing intensity of light at increasing depths. It is interesting to note that in general there is a definite relation between the color of the algæ and the light stratum which they inhabit. The green algæ (Ulva, Enteromorpha, etc.) are chiefly in the upper stratum, the brown algæ (Laminaria, etc.) chiefly in the middle one, and the red algæ chiefly in the lower. Yet the relation between the color of the algæ and the light stratum which they inhabit is not as definite as was once supposed. The red algæ, however, are especially adapted to growing in the more dimly lighted stratum of the photic region, since they are sensitive

to light and suffer decoloration in the stronger-lighted strata. In shady places the red algæ grow nearer the surface; some

Fig. 533*b*.
Ascophyllum nodosum at low tide, Hunter's Island, New York City. (Photograph by M. A. Howe.)

species are bright red when they grow in the shade or dull red when growing in brighter light.

CHAPTER LVII.

PRACTICAL STUDY OF PLANT FORMATIONS.

I. Suggestions for Practical Study of Plant Formations.*

1119. The space is too limited in this work to present an elaborate or even complete plan for study of plant formations. The purpose is to offer merely some plain suggestions to those who wish to make a general survey of plant formations in a given region where time is limited or where it is desired to do this as a supplement to the elementary botanical work of the school. It is needless to say that the student should have had a good course in elementary plant physiology and general morphology, since these subjects are fundamental to the study of the relation of vegetation to its environment.

For independent study of plant formations more than an elementary knowledge of these subjects is necessary, as well as a good working knowledge of plant classification. This the elementary student cannot possess, and yet it is possible to learn many useful and practical things concerning plant life which will not only aid one in interpreting the relations of vegetation to natural surroundings, but will give a broader view of nature.

The work should be done under the guidance of the teacher. Even if the students know but few plants, it will be possible for them to discover striking formations where the individuals of one or several species are massed together over a considerable area so that they form the dominant vegetation of the area. They can be told the name of the plant unless it is possible for them to discover it for themselves, and it should be borne in mind that it is more important to discover a life relation of the plant in this way than it is to merely determine the name of the plant. Then the prominent plant formations can be worked out for several different

* See Suggestions for Teacher, foot-note page 349, Chapter XXXVIII.

physiographic areas. It should be borne in mind always that all associations of plants do not represent distinct formations. Some formations may be incipient and others decadent and thus difficult to determine; also more or less extensive areas may have a mixture of several formations over a transition area. Again, mere patches representing a gregarious condition of certain species within another formation should not be mistaken for a formation.

The district selected for study should, if possible, include forest, low marshy areas, and ponds or lakes, within which area will probably occur a number of different soil conditions, as rocky, sandy, or clayey areas, etc., ravines, bluffs, meadows, etc. It might be well to follow the plan of mapping the area, or of mappi g the distinct physiographic areas studied when they are far separated, and indicating the location and extent of different formations, with notes on kind of soil (gravel, sandy, rocky, loamy, etc.), and in general the relation of the formations to topography, i.e., to different degrees of the gradient of slope where there is radial or lateral topographic symmetry, as on hillsides or borders of streams, or ponds, etc., different depths of water, etc. Topographic maps already in existence can be used or made the basis of the special chart. The topographic maps now being issued by the United States Geological Survey* are most excellent for use and reference in connection with this study.

The district studied would, of course, be more or less limited. In connection with the work studies of literature, or lectures should connect the work with larger districts and with the great climatic formations, or vegetaiton provinces, or regions (See Section II of this chapter).

Suppose the district to be studied lies within the woodland climate. For practical purposes of an elementary study this could be divided into mountain districts, and coastal plain, and continental valley districts, since in a mountain region one would be chiefly concerned with problems somewhat different from those of the coastal plains or continental valleys, and the two sets of districts could only be studied together in actual practice when the work was extended over a long period. For the purpose of subdividing a large area and getting at the chief physiographic areas which are the units of the principal formations the more level districts of the woodland climatic region might be divided as follows:

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* From the U. S. Geological Survey at Washington, D. C., can be obtained a map showing on a small scale the districts covered for each State and indicating which ones are completed, as well as the price. By securing this map one can easily determine the topographic maps needed to cover the area selected for study.

1120. Woodland climatic region.

Coastal Plain and Continental Valley Districts. Physiographic Divisions.

Forested Areas.		*Non-forested Areas.*	
Series of Formations.	Principal Formations.	Series of Formations.	Principal Formations.
1. Upland series.	Rock hill. Gravel hill. Sand hill. Clay hill.	1. Edaphic series.	Mud or reed swamp. Sphagnum moor. Heath moor. Tamarack swamp. Meadows. Rocky places. Sandy strand and dunes. Salt marsh. Alkali lands. Shores of marl ponds.
2. Lowland series.	Rock areas. Gravel areas. Sand areas. Clay areas. Loam areas.	2. Aquatic series.	Streams. Ponds. Lakes. Salt seas. Ocean. Brackish waters. Marl ponds.
3. River series.	Ravine. River bluff. Flood plain. Mature river valley.	3. Culture series.	Cultivated places. Waste places.
4. Swamp series.	Mangrove swamp. Heath moor. Mud swamp. Water swamp. Tamarack swamp. Cypress swamp.	(No attempt is made here to subdivide the culture series.)	
5. Coastal series.	Lake bluff. Ocean bluff. Sand strand or dunes. Humus strand. Coastal swamp.		

New features and combinations will present themselves in each district studied. The above outline must be modified to suit the particular case. In some cases formations in the district may not be represented. Special formations may occur not explicitly referred to in the synopsis. The discovery and elaboration of these regions would be especially interesting.

1121. In the mountain districts, besides the physiographic divisions the climatic divisions would be noticeable within short distances as compared with the more level districts. A general subdivision might be made as follows:

Montane Districts.

1. Valley series.
2. Foothill series.
3. Basal series.
4. Montane series.
5. (Alpine series beyond tree growth).

In general physiographic divisions might be made similar to those given in the table above for the more level districts, though modifications and additions would be necessary when an actual survey of the district is made. So in the following climatic regions a similar physiographic division might be made, but some alterations and additions would be necessary because of changed conditions of environment. For example, the oases in deserts and plains, the warm oases, and the tundra in arctic regions, and so on.

Prairie climatic region.
Plains climatic region. } Grassland climatic region of Schimper.
Arctic climatic region.

While the physiographic subdivisions of districts outlined above is only suggested as a basis for an elementary practical study of vegetation of local regions, the locality should be asssigned its proper place in some one of the several plans proposed for the purpose of dividing the vegetation surface of the earth into large natural areas based either on physiographic or climatic conditions or both. See Section II of this chapter.

1122. *Formations* (=*association of some students*).—Having looked over the locality or district to be studied, and having prepared a chart showing the distinct physiographic areas or edaphic areas to be examined in detail, these principal formations can then be critically studied for the purpose of determining the individual formation, or formations (=associations of some students).

1123. *Dominant species in a formation.*—(1) Determine the different formations with the one or more dominant species.

(2) Chart its extent and limits in the locality or principal formation.

(3) If there are evident layers (as in a forest or heath), determine the prominent ones.

(4) Where there is a slope providing a regular succession of series of different soil conditions or water content, or a sloping shore and water basin, determine the zones (or lateral layers) indicated by the different individual formations down the sloping bank and gradually out into the deep water. Even where topographic conditions are the same the ground may be occupied by different species in different regions or at different points along the same shore. All these peculiarities should be noted and the formations of different lakes, ponds, etc., compared. For example, in fig. 534 are shown several zonal formations. Beginning at the highest

Fig. 534.
Zonal distribution of plants, south shore of Cayuga Lake. See text (Photograph by the author.)

point on the land these are in succession: white pine (1), oak (2), willows (3), thoroughwort (4): littoral zone of semi-aquatics, typha (5), bulrushes (6), arrow-leaf (7); mid zone, pond-lilies and potamogetons (8); Sub-

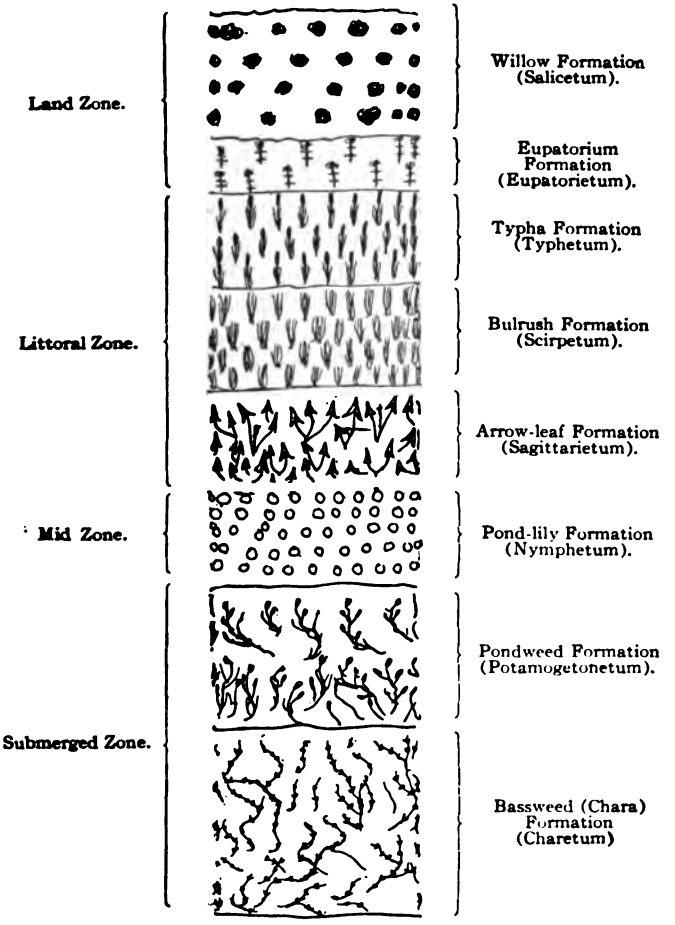

Fig. 535.

Chart showing relative position of plant formations in zones along lake shores.

merged zone, pondweeds (Potamogeton and Vallisneria, 9), bassweed (Chara, 10). By the side of this, on the same shore, the typha is replaced by sedges, and the arrow-leaf by the yellow water lily or spatter-dock (Nu-

phar advena), while in some other places the latter is replaced by the white water-lily (Nymphæa odorata). These could be charted as in fig. 535.

(5) Note the prominent physical characteristics of the soil.

(6) Note exposure to sun, wind, etc., if so situated as to be especially influenced by these.

1124. Secondary or subordinate species in a formation.—Give special attention to those species which are characteristic of similar physiographic areas.

(1) Species which occupy similar ground in other districts where they may become dominant species in the formation (example, cranberries occur as scattered individuals in some moors or bogs, while in others they are dominant species in the formation, so it is with the cattail-flag in swamps, and with many other plants).

(2) Species which are characteristic of certain localities but are never abundant enough to dominate the formation (examples: the pitcher plant, sundews, etc., in moors).

(3) Species which are infiltrated in with the dominant vegetation of a formation and mark this portion off from other patches of the same formation (example, in rolling prairies or grass-land, different flowers on different kinds of soil or where there is a slight variation in soil moisture).

(4) Guilds (or associates or companions) (examples: Lianas [scramblers, climbers, root-climbers], etc.), epiphytes (examples: Lichens, mosses, etc.).

(5) Parasites (examples: parasitic fungi on leaves, fruit, flowers, trunks, etc., parasitic flowering plants, as dodder, etc.).

(6) Wood-destroying fungi.

(7) Humus-forming fungi, and so on.

1125. The general features of the study the teacher can illustrate.—1st. By lantern slides of photographs of vegetation and formations of different regions not illustrated in the local flora (examples: desert, arctic, alpine, prairie, plains, forests of different kinds, edaphic series of various kinds).

2d. By photographs illustrating different physiographic areas, or edaphic series, or principal formations, to be studied in the selected locality. These will also show many individual formations in zones or areas. The negatives could be used to make velox prints or blue prints for members of the class to illustrate their study, each student purchasing a set.

3d. It is desirable, so far as possible, to have at least a small collection of plants especially made to illustrate various features of the study (examples: plants from arctic, alpine, desert, and other regions, especially such as will illustrate such characters as fit them to exist under the peculiar conditions, as well as to illustrate plants which are dominant elements of characteristic formations). In some cases these can be obtained by purchase or exchange. In addition the teacher can work each year toward making a collection of local plants for the purpose of illustrating the various phases

of the subject. In this work the teacher can probably enlist the cooperation of some of the students. In many cases photographs will illustrate certain features of the plant not well shown in a dried specimen, and the photograph can accompany it. Access to greenhouses will enable the teacher to further illustrate the subject.

1126. The student should so far as possible keep a neat record, brief, but to the point, of his work. This record should be supplemented by preserved plants, or good photographs of the plants (or both), the notes indicating the principal and individual formations to which it belongs, whether a dominant species in a formation, whether alone or coordinate with other species (preserve and cite them), or if a subordinate species then note what relation it bears to the formation or the locality; also a

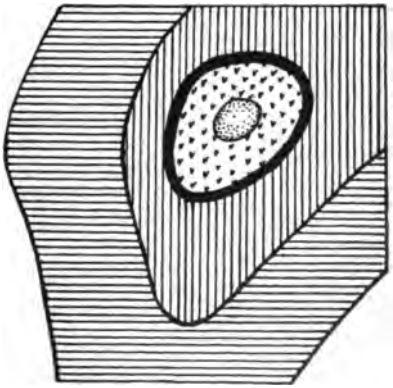
5 Ridges with *Pinus divaricata.*
4 Zone of *Larix laricina.*
Zone of *Picea Mariana.*
2 Zone of *Ledum* and *Eriophorum.*
1 Central *Sphagnum* and *Utricularia.*

Fig. 536.
McMillan, Bull. Torr. Bot. Club, p. 502, 1896.

few notes to indicate kind of soil (or depth, etc., of water in case of aquatics); and a reference to a photograph where possible to show character of formation and surroundings. With a numbered series of photographs, one print would do duty in some cases for citation of several or a large number of species. Cards or blank paper 5×8 inches might be used by the students to keep their record, one card or slip for each species, the

name being written in the upper left-hand corner, and these cards could then be kept in card-catalogue order. When necessary notes and references could be continued on back.

1127. Simple way to chart extent and relation of plant formations.—There are several simple ways of charting the location and extent of plant formations. One method of illustrating the relation of formations to each other is shown in fig. 535. The relation and extent of formations may be illustrated as shown in fig. 536 (from MacMillan, Bull. Torr. Bot. Club, **23**, p. 502, 1896), and as shown by Pieters (The Plants of Lake St. Clair, Bull. Mich. Fish Comm., No. 2, 1894, Lansing), by Ganong (Vegetation of Bay of Fundy Marshes, Bot. Gaz., **36**, p. 351, 1903), and others.

II. Natural Vegetation Regions of the Earth.

1128. According to Griesebach.—The regions established by Griesebach were based on the notion of separate centers of development and distribution of the vegetation of the land.

Twenty-four regions were recognized:

I. Arctic region.
II. Forest region of the Eastern Continent.
III. Mediterranean region.
IV. Region of the Asiatic Steppes.
V. Chinese-Japanese region.
VI. Indian-Malayan region.
VII. Sahara region.
VIII. Soudan, or Central Africa, region.
IX. Kalahari region.
X. Cape of Good Hope region.
XI. Australian region.
XII. Forest region of the Western Continent.
XIII. Prairie region.
XIV. Californian Coast region.
XV. Mexican region.
XVI. West Indies region.
XVII. Cisequatorial South American region.
XVIII. Hylæa, or Amazonian, region.
XIX. Brazilian region.
XX. Tropical Andes region.
XXI. Pampas region.
XXII. Chilean transition region.
XXIII. Antarctic forest region.
XXIV. Oceanic Island region.

1129. According to Engler.—Engler's classification is based on the notion of general development and migration. He recognizes four great realms, which are then divided into a large number of regions and provinces. Only those regions and provinces will be given here which apply to North America,

1. THE REALMS AND THE REGIONS IN NORTH AMERICA.

World-realms.	Region in North America.
A. Northern extratropical Realm..	(1) Arctic region (also in Europe).
	(2) Subarctic or Conifer region (also in Europe).
	(8) Pacific N. A. region.
	(9) Atlantic N. A. region.

World-realms.	Region in North America.
B. Tropical old-world Realm.	
C. South American Realm.....	(1) Mexican highland region. (2) Tropical American region. (These parts of North America are considered as belonging to the Southern Realm.)
D. Old Oceanic Realm.	

2. PROVINCES IN NORTH AMERICA.

(1) Arctic Region, not subdivided.

(2) Subarctic, or Conifer Region (only those in North America given).

(*c*) North American Lake Province (unites on the north with the arctic region and on the south with the Pacific and Atlantic regions of North America).

The regions of the North American continent come under two realms, as is noted above. Mexican highlands and Central America botanically belong rather with South than with North America. (Three zones are recognized: I, the Algonquin zone, lying between Hudson Bay, Newfoundland and Lake Superior, characterized by Thuja occidentalis and Taxus canadensis; II, Athabasca zone, bounded on the south by a line from Hudson Bay to the Rocky Mountains and characterized by Pinus banksiana, Abies balsamea, Picea nigra, Larix pendula, Picea alba; III, Canadian zone, not clearly delimited, lying southward of the other two and between them, including Manitoba, western Ontario, northern Minnesota, Wisconsin and Michigan, characterized by Pinus strobus, Pinus resinosa, and Abies canadensis.)

(3) Pacific North American Region. (Reaching from the sea to the foot of the Rocky Mountains, and south to the Mexican highlands.)

(*a*) Californian coast province (between the Coast Range, and the sea. Characteristic conifers, Sequoia sempervirens, Pinus insignis, Pinus muricata, Pinus tuberculata, Pinus coulteri, Picea bracteata, Torreya californica, Cupressus macnabiana, Cupressus macrocarpa).

(*b*) Oregon province. (Including area west of Cascade Mountains.) Four zones are recognized: I, Kaloschen zone, to 52° north latitude, characterized by Thujopsis borealis; II, Douglas zone, to 43° north latitude, characterized by Abies douglasii; III, Umpqua zone, between 42° or 43° north latitude, characterized by Cupressus fragrans; IV, Sierra zone, characterized by Pinus lambertiana and Sequoia gigantea (=S. washingtoniana).

(*c*) Rocky Mountain province. (Characterized by Pinus flexilis, Pinus monophylla, Larix occidentalis, etc.)

(*d*) Colorado province. (Reaching from Cascade to Rocky Mountains, open country).

(4) Atlantic North American Region.

(*a*) Appalachian province. (The forest district of the Atlantic North American region south of the lake province includes three zones: I, Alleghany zone, characterized by Pinus inops, Pinus pungens, Pinus rigida, Picea fraseri, Juniperus virginiana; II, Carolina zone, including New Jersey, Delaware, Maryland, Pennsylvania, Virginia, Georgia; III, Mississippi zone, including the forest district of the Mississippi valley.)

(*b*) Prairie province. (The western central and central prairies of the Atlantic drainage, including also the Saskatchewan and Assiniboian prairies of Arctic Ocean drainage.)

1130. According to Drude.—This is one of the most recent and generalized divisions of the earth into botanical realms and regions, and is used by MacMillan, Pound and Clements, and others.

THE FLORAL REGIONS OF CONTINENTS AND ISLANDS.

Realms.	Regions.
A. Northern Realm.....	(1) Arctic region. (2) Northern region. (3) Middle Norh American region. (4) Mediterranean-Oriental region. (5) Lower Asian region. (6) East Asian region.
B. Tropical Realm.....	(1) Tropical American region. (2) Tropical African region. (3) Indian region. (4) Malayan-New Zealand region.
C. Southern Realm.....	(1) Andes region. (2) South African region. (3) Australian region. (4) Antarctic region.

THE FLORAL REGIONS OF THE OCEAN.

Only one realm in the ocean is recognized.
The regions are as follows:

A. Northern.

1. Arctic coasts.
2. North Atlantic coasts.
3. North Pacific coasts.

B. Tropical.

4. Mediterranean coasts.
5. Tropical Atlantic coasts.
6. Indian coasts.
7. Tropical-Pacific coasts.

C. Southern.

8. Australian coasts.
9. Antarctic coasts.

1131. According to Merriam.—The most recent arrangement of vegetation regions as applied to North America are the life zones and areas of Merriam, which are based on the climatic factors, temperature and moisture, the influence of temperature being most important during the period of growth and reproduction. These life zones and areas have been worked out more largely with reference to animals, though plants have been considered also, and Merriam believes that the distribution of plants as well as animals is limited by these life zones. For a discussion of them see Chapter XLVIII; see also fig. 492.

1. LIFE ZONES AND AREAS OF NORTH AMERICA.

Regions.	Zones.	Areas.
Boreal	Arctic, or Arctic-alpine.	
	Hudsonian.	
	Canadian.	
Austral	Transition	Alleghanian.
		Arid transition.
		Pacific coast transition.
	Upper Austral	Carolinian.
		Upper Sonoran.
	Lower Austral	Austroriparian.
		Lower Sonoran.
	Semitropical Gulf strip.	
Tropical		Humid tropical.
		Arid tropical.

2. CHARACTERISTICS OF THE ZONES AND AREAS.

1132. Briefly the limits and characteristic plants of the zones and areas are as follows:

BOREAL REGION.—There are three natural belts.

1. *Arctic or Arctic-Alpine Zone.*—This is the northernmost belt and lies beyond the limit of tree growth. The larger part is perpetually covered with snow and ice. It is characterized by extensive fields of mosses, by the arctic poppy, dwarf willows and various saxifrages, as well as other arctic plants, and by some writers is called the hyperboreal region. Within the United States the Arctic-Alpine zone is restricted to the area above timber line on the summits of high mountains. It is inhabited by arctic-alpine plants and animals, and is far too cold for agriculture.

2. *The Hudsonian Zone.*—This is a subarctic zone embracing the most northern part of the great transcontinental coniferous forests—a forest of spruces, firs, birches, and aspens, stretching from Labrador to Alaska in the region of Hudson's Bay. By its position it is sometimes called

the Northern Foerst, or because of the large number of lakes in the zone, the Lacustrian Forest of the North. It includes also the upper timbered slopes of the higher mountains of the United States and Mexico. In the eastern United States the Hudsonian zone is restricted to the cold summits of the highest mountains, where it occurs in the form of a chain of widely separated islands reaching from northern New England to western North Carolina. Like the preceding, this zone is of no agricultural importance.

3. *The Canadian Zone.*—The Canadian zone comprises the southern part of the great transcontinental coniferous forest of Canada, the northern parts of Maine, New Hampshire, and Michigan, a strip along the Pacific coast reaching as far south at least as Cape Mendocino in California, and the greater part of the high mountains of the United States and Mexico. In the east it covers the Green Mountains, Adirondacks, and Catskills, and the higher mountains of Pennsylvania, West Virginia, Virginia, western North Carolina, and eastern Tennessee. In the mountains of the east it covers the lower slopes in the north and the higher slopes in the south. In the Rocky Mountain region it appears to reach continuously from British Columbia to west central Wyoming; and in the Cascade Range, from British Columbia to southern Oregon, with a narrow interruption along the Columbia River. Pines, spruces, firs, hemlock spruce, larches, etc., outnumber the broad-leaved deciduous trees. Counting from the north, this zone is the first of any agricultural importance. Wild berries—as currants, huckleberries, blackberries, and cranberries—grow in profusion, and the beechnut (in the east) is an important food of the native birds and mammals. In favored spots, particularly along the southern border, white potatoes, turnips, beets, and the more hardy Russian apples and cereals may be cultivated with more moderate success.

THE AUSTRAL REGION.—This includes three zones and seven areas.

Transition Zone.—As its name indicates, this zone is the ground where the boreal and austral types meet. The forests are chiefly of deciduous trees which grow in the cooler austral belt.

a. Alleghanian Area.—This is the humid eastern division. It extends from the coast of New England across New York, Pennsylvania, southern Ontario, Michigan, Wisconsin, Minnesota, and the Dakotas, when it meets the dry, grassy plains of the west. In the east it reaches southward in a long arm including the Alleghany Mountains to Georgia. Oaks, hickories, chestnuts, locusts, birches, aspens, ash, and mountain ash mingle with the northern spruces, hemlock spruce, pines, and other coniferous trees from the south, while the shrubby undergrowth is characterized by azaleas, rhododendrons, andromedas, and other heaths. Oats, rye, wheat, Indian corn, the potato, onion, root crops like the beet, carrot,

turnip, etc., are cultivated, while orchard crops like apples, peaches, cherries, pears, plums, and a variety of berries are common.

b. The Arid Transition Area.—"The western or arid division of the Transition zone comprises the western part of the Dakotas, northern Montana east of the Rocky Mountains, southern Assiniboia, small areas in Manitoba and Alberta, the higher parts of the Great Basin and the plateau region generally (except the boreal mountain areas), the eastern base of the Cascade-Sierra system, and local areas still farther west, in Oregon and California, where it merges into the humid Pacific Coast division." The prevailing type of vegetation is the true sage-brush (Artemisia tridenta) with extensive tracts of the yellow or bull pine. Wheat, oats, barley, corn, apples, cherries, grapes, pears, plums, potatoes, sugar-beets, etc., are cultivated.

c. The Pacific Coast Transition Area.—"The humid Pacific Coast division of the Transition zone comprises the western parts of Washington and Oregon between the coast mountains and the Cascade Range, parts of northern California from near Cape Mendocino southward to the Santa Barbara Mountains. To the south and east it passes into the Arid Transition, and in places into the Upper Sonoran." This region, as a whole, is one of great humidity. "The northern and more humid part is covered by a magnificent coniferous forest, carpeted with moss and ferns, and often choked with undergrowth. The prevailing trees are Douglas fir, Pacific cedar, western hemlock, and Sitka spruce, whose majestic trunks attain an average height of more than 200 feet. There are also many broad-leaf maples, tree-alders, madronas and western dogwoods, and numerous kinds of shrubs," as sabal (Gaultheria shallon), thimble-berry (Rubus nootkanus), Oregon grape (Berberis nervosa), and devil's-club (Echinopanax horridula).

"The region as a whole is one of relatively uniform temperature, the wide seasonal differences usual in other parts of the Transition zone being unknown. The temperature of the summer season, the hottest part of the year, is phenomenally low for the latitude, enabling northern or boreal types to push south as far as latitude 35°. On the other hand, the summer season is so prolonged (from the standpoint of temperature) that the total quantity of heat for the entire season is phenomenally high for the latitude, enabling southern or austral species to push north as far as Puget Sound, where the total quantity of heat is even greater than at Philadelphia, Pittsburg, Cleveland, and Omaha, although Puget Sound is 500 miles north of the latitude of these places. Even at Cape Flattery—the extreme northwestern point of the United States—which is exposed throughout the year to the cold coast fogs, the total quantity of heat is 500° F. greater than at Eastport, Maine, although the latter is the more southern locality and has the higher mean summer temperature. The low summer temperature

along the Pacific coast permits northern species to come far south, while the high sum total enables southern species to push northward as far as Puget Sound. Such an extensive overlapping of Boreal and Austral faunas does not occur elsewhere in North America, and for the evident reason that no area approaching it in extent has so equable a temperature.

"In most parts of the United States it is easy to distinguish the boundaries between the Transition and Upper Austral zones, but in the Pacific Transition area these distinctions are nearly obliterated, a large portion of the species ranging in common over both belts."

The Upper Austral Zone.—"The Upper Austral zone may be divided into two large and important faunal areas—an eastern humid or Carolinian area and a western arid or Upper Sonoran area, which pass insensibly into one another in the neighborhood of the one-hundredth meridian."

a. The Carolinian Area.—"The Carolinian area occupies the larger part of the Middle States, except the mountains, covering southeastern South Dakota, eastern Nebraska, Kansas, and part of Oklahoma; nearly the whole of Iowa, Missouri, Illinois, Indiana, Ohio, Maryland, and Delaware; more than half of West Virginia, Kentucky, Tennessee, and New Jersey, and large areas in Alabama, Georgia, the Carolinas, Virginia, Pennsylvania, New York, Michigan, and southern Ontario. On the Atlantic coast it reaches from near the mouth of Chesapeake Bay to southern Connecticut, and sends narrow arms up the valleys of the Connecticut and Hudson rivers. A little farther west another slender arm is sent northward, following the east shore of Lake Michigan nearly or quite to Grand Traverse Bay. These arms, like nearly all narrow northern prolongations of southern zones, do not carry the complete faunas of the areas to which they belong, but lack certain species from the start and become more and more dilute to the northward until it is hard to say where they really end. Their northward boundaries, therefore, must be drawn arbitrarily or must be based on the presence of particular species rather than the usual associations of species.

"Counting from the north, the Carolinian area is that in which the sassafras, tulip-tree, hackberry, sycamore, sweet gum, rose-magnolia, redbud, persimmon, and short-leaved pine first make their appearance. Chestnuts, hickory-nuts, hazelnuts, and walnuts grow wild in abundance. The area is of very great agricultural importance.

"Cereals do well in the Carolinian area, particularly wheat and corn. The sugar-beet is an important crop in the northern parts, but fails to develop sufficient sugar for profitable culture in the southern parts."

b. The Upper Sonoran Area.—"It covers most of the great plains in eastern Montana and Wyoming, southwestern South Dakota, western Nebraska, Kansas, Oklahoma and Texas, and eastern Colorado and New Mexico. In Oregon and Washington it covers the plains of the

Columbia and the Malheur and Harney plains; in California it encircles the Sacramento and San Joaquin valleys and forms a narrow belt along the eastern boundary of the Colorado and Mohave deserts; in Utah it covers the Salt Lake and Sevier deserts, in Idaho the Snake Plains, and in Nevada and Arizona irregular areas of suitable elevation. Except in California the most conspicuous vegetation of the Upper Sonoran areas is the true sage-brush (Artemisia tridentata), which, however, is equally abundant in the Transition zone. Several of the so-called 'greasewoods' (Atriplex confertifolia, A. canescens, A. nuttallii, Tetradymia canescens, Sarcobatus vermiculatus, and Grayia spinosa) are on characteristic soils; and nut-pines (pinon) and junipers occur here and there, mostly on the mountain slopes.

"The Upper Sonoran area, notwithstanding its aridity, is of considerable agricultural importance. Fruits and cereals succeed wherever water may be had for irrigation, and in the less arid parts wheat, corn, barley, and rye yield their heaviest returns. Kaffir corn (a kind of millet) thrives without irrigation, particularly on the great plains, and alfalfa with irrigation matures several crops a year, though not so many as in the Lower Sonoran."

The Lower Austral Zone.—"The Lower Austral zone occupies the southern part of the United States, from Chesapeake Bay to the great interior valley of California. It is interrupted by the continental divide in eastern Arizona and western New Mexico, and is divided into an eastern or Austroriparian, and a western or Lower Sonoran, area."

a. The Lower Sonoran area.—"The Lower Sonoran area begins with the arid region of Texas in the neighborhood of latitude 98°, and stretches westerly to the Rio Grande Valley, in which it sends an arm northwest to a point a little north of Albuquerque, New Mexico. Another arm reaches up the valley of the Pecos. West of the Rio Grande Valley in New Mexico the Lower Sonoran is interrupted by the continental divide. It begins again in eastern Arizona and sweeps broadly westward below the high plateau, covering southern and western Arizona, the deserts of southern Nevada and eastern California, and the San Joaquin and Sacramento valleys. Followed more in detail, the Lower Sonoran in western Arizona sends a narrow, tortuous arm eastward in the Grand Cañon of the Colorado, which expands to cover the lower levels of the Painted Desert, and another arm northward, which enters the extreme southwestern corner of Utah, where it is restricted to the St. George or lower Santa Clara Valley, and is of much agricultural importance. From western Arizona it spreads over southern Nevada, pushes northerly into Pahranagat Valley, sends an arm by way of Oasis and Sarcobatus valleys all the way to the sink of the Humboldt and Carson rivers, fills the whole of Death, Panamint, and Saline valleys and part of Owens Valley, and thence curving

southwesterly follows the eastern base of the Sierra Nevada, Techahapi, and Tejon mountains, and covers the whole of the Mohave and Colorado deserts and all the rest of southern California except the mountains. It sends an arm over most of the peninsula of Lower California, and another northward over the San Joaquin and Sacramento valleys.

"The Lower Sonoran area comprises the most arid deserts of North America, and is characterized by a flora and fauna of extreme interest. Among the commoner plants are the creosote bush, mesquites, acacias, cactuses, yuccas, and agaves. . . . The region, wherever water may be had for irrigation, is of great agricultural importance, particularly for fruit.

"Raisins and wine grapes, oranges, lemons, olives, prunes, peaches, apricots, English walnuts, and almonds are among the important products of the Lower Sonoran area, and the figs ripen several crops each year. Although too far south for the highest development of cereals, several kinds, as the Australian and Sonoran wheats, the red rust-proof oats, and the white-gourd seed corn, do well. Cotton, tobacco, pyrethrum, and the opium poppy thrive in certain localities, and alfalfa, cow-peas, and canaigre (a plant valuable for tanning) do better than in any other area."

b. The Austroriparian area.—"The Austroriparian area occupies the greater part of the South Atlantic and Gulf States. Beginning near the mouth of Chesapeake Bay it covers half or more than half of Virginia, North and South Carolina, Georgia, Florida, Alabama, the whole of Mississippi and Louisiana, eastern Texas, nearly all of Indian Territory, more than half of Arkansas, and parts of Oklahoma, southwestern Kansas, southeastern Missouri, southern Illinois, the extreme southwestern corner of Indiana, and the bottom lands of western Kentucky and Tennessee. The long-leaf and loblolly pines, magnolia, and live oak are common on the uplands; the bald cypress, tupelo, and cane in the swamps. . . . This is the zone of the cotton plant, sugar-cane, rice, pecan, and peanut, and of the scuppernong grape and oriental pears (LeConte and Kieffer)."

c. The Semitropical or Gulf strip.—"The Gulf strip, or southern part of the Austroriparian area reaches from Texas to southern Florida, covers a narrow strip in southern Georgia, and probably follows the coastal lowlands northward into South Carolina. It has a semitropical climate and is the home of a number of plants not found farther north, among which are the cabbage palmetto and Cuban pine. . . . The Gulf strip, though small in area, is of very great importance from the standpoint of agriculture and horticulture. It is the belt in which rice, sugar-cane, and the much-prized sea-island cotton are produced in greatest quantity and value; and, as a fruit belt, has no competitor, except the Lower Sonoran areas of California and Arizona. Bitter oranges, loquats, granadillas, figs, Japanese persimmons, pecan nuts, and numerous varieties of peaches and grapes thrive here, and the citrus fruits (oranges, mandarins, lemons,

limes, and shaddocks) are grown successfully in the warmer parts, particularly in peninsular Florida, but in the northern parts have suffered severely from frosts."

THE TROPICAL REGION.—"The tropical region within the United States is of small extent and is restricted to three widely separated localities—southern Florida, extreme southeast Texas (along the lower Rio Grande and Gulf coast), and the valley of the lower Colorado River in Arizona and California. The Florida area is genuine humid tropical; the Texas and Arizona-California areas are dilute arid tropical. Among the tropical trees that grow in southern Florida are the royal palm, Jamaica dogwood, manchineel, mahogany, and mangrove. . . . The extension of the arid tropical along the lower Colorado and Gila rivers is over a desert region of excessive aridity. . . . The flora has not been sufficiently studied, but is characterized by giant cactuses, desert acacias, palo verdes, and the Washington or fan-leaf palm.

"With irrigation the arid tropical areas are found to be as productive as the humid tropical, but they have been cultivated so short a time that their capabilities can only be inferred from the circumstance that bananas, citrons, dates, guavas, lemons, loquates, oranges, and Mexican limes do well in the Arizona-California arm. No information is at hand relating to the Texan or Tamaulipan arm."

PART V.

REPRESENTATIVE FAMILIES OF ANGIOSPERMS.

CHAPTER LVIII.

RELATION OF SPECIES, GENUS, FAMILY, ORDER, ETC.*

1133. Species.—It is not necessary for one to be a botanist in order to recognize, during a stroll in the woods where the trillium is flowering, that there are many individual plants very like each other. They may vary in size, and the parts may differ a little in form. When the flowers first open they are usually white, and in age they generally become pinkish. In some individuals they are pinkish when they first open. Even with these variations, which are trifling in comparison with the points of close agreement, we recognize the individuals to be of the *same kind*, just as we recognize the corn plants, grown from the seed of an ear of corn, as of the same kind. Individuals of the same kind, in this sense, form a *species*. The white wake-robin, then, is a species.

But there are other trilliums which differ greatly from this one. The purple trillium (T. erectum) shown in fig. 537 is very different

* Chapters XXXVIII–XLV should be studied in connection with the following lessons on families of the angiosperms (in Chapters LIX–LXV), but especially should Chapters XLII, XLIII, and XLIV be consulted. See also Chapter LXVI for the arrangement of families, orders, etc., in classification. See also "Suggestions for the teacher," foot of page 349, Chapter XXXVIII; see also Chapter LVII.

from it. So are a number of others. But the purple trillium is a species. It is made up of individuals variable, yet very like one another, more so than any one of them is like the white wake-robin.

Fig. 537. Trillium erectum (purple form), two plants from one rootstock.

1134. Genus. — Yet if we study all parts of the plant, the perennial rootstock, the annual shoot, and the parts of the flower, we find a great resemblance. In this respect we find that there are several species which possess the same general characters. In other words, there is a relationship between these different species, a relationship which includes more than the individuals of one kind. It includes several kinds. Obviously, then, this is a relationship with broader limits, and of a higher grade, than that of the individuals of a species. The grade next higher than species we call *genus*. Trillium, then, is a genus. Briefly the characters of the genus trillium are as follows:

1135. Genus trillium.—Perianth of six parts: sepals 3, herbaceous, persistent; petals colored. Stamens 6 (in two whorls), anthers opening inward. Ovary 3-loculed, 3–6-angled; stigmas 3, slender, spreading. Herbs with a stout perennial rootstock, with fleshy, scale-like leaves, from which the low annual shoot arises, bearing a terminal flower and 3 large netted-veined leaves in a whorl.

Note.—In speaking of the genus the present usage is to say trillium, but two words are usually employed in speaking of the species, as Trillium grandiflorum, T. erectum, etc.

1136. Genus erythronium.—The yellow adder-tongue, or

dogtooth violet (Erythronium americanum), shown in fig. 538, is quite different from any species of trillium. It differs more from any of the species of trillium than they do from each other. The perianth is of six parts, light yellow, often spotted near the base. Stamens are 6. The ovary is obovate, tapering at the base, 3-valved, seeds rather numerous, and the style is elongated. The flower stem, or scape, arises from a scaly bulb deep in the soil, and is sheathed by two elliptical-lanceolate, mottled leaves. The smaller plants have no flower and but one leaf, while the bulb is nearer the surface. Each year new bulbs are formed at the end of runners from a parent bulb. These runners penetrate each year deeper in the soil. The deeper bulbs bear the flower stems.

Fig. 538.

Adder-tongue (erythronium). At left below pistil, and three stamens opposite three parts of the perianth. Bulb at the right.

1137. Genus lilium.—While the lily differs from either the trillium or erythronium, yet we recognize a relationship when we compare the perianth of six colored parts, the 6 stamens, and the 3-sided and long 3-loculed ovary.

1138. Family Liliaceæ.—The relationship between genera, as between trillium, erythronium, and lilium, brings us to a still

higher order of relationship, where the limits are broader than in the genus. Genera which are thus related make up the *family*. In the case of these genera the family has been named after the lily, and is the lily family, or *Liliaceæ*.

1139. Order, class, group.—In like manner the lily family, the iris family, the amaryllis family, and others which show characters of close relationship are united into an *order* which has broader limits than the family. This order is the lily order, or order *Liliales*. The various orders unite to make up the *class*, and the classes unite to form a *group*.

1140. Variations in usage of the terms class, order, etc.—Thus, according to the system of classification adopted by some, the angiosperms form a *group*. The group angiosperms is then divided into two *classes*, the *monocotyledones* and *dicotyledones*. (It should be remembered that all systematists do not agree in assigning the same grade and limits to the classes, subclasses, etc. For example, some treat of the angiosperms as a class, and the monocotyledons and dicotyledons as subclasses; while others would divide the monocotyledons and dicotyledons into classes, instead of treating each one as a class or as a subclass. Systematists differ also in usage as to the termination of the ordinal name; for example, some use the word *Liliales* for *Liliiflorœ*, in writing of the order.)

1141. Monocotyledones.—In the monocotyledons there is a single cotyledon on the embryo; the leaves are parallel veined; the parts of the flower are usually in threes; endosperm is usually present in the seed; the vascular bundles are usually closed, and are scattered irregularly through the stem as shown by a cross-section of the stem of a palm (fig. 539), or by the arrangement of the bundles in the corn stem (fig. 57). Thus a single character is not sufficient to show relationship in the class (nor is it in orders, nor in many of the lower grades), but one must use the sum of several important characters.

1142. Dicotyledones.—In the dicotyledons there are two cotyledons on the embryo; the venation of the leaves is reticulate; the endosperm is usually absent in the seed; the parts of the

flower are frequently in fives; the vascular bundles of the stem are generally open and arranged in rings around the stem, as shown in the cross-section of the oak (fig. 539). There are exceptions to all the above characters, and the sum of the characters must be considered, just as in the case of the monocotyledons.

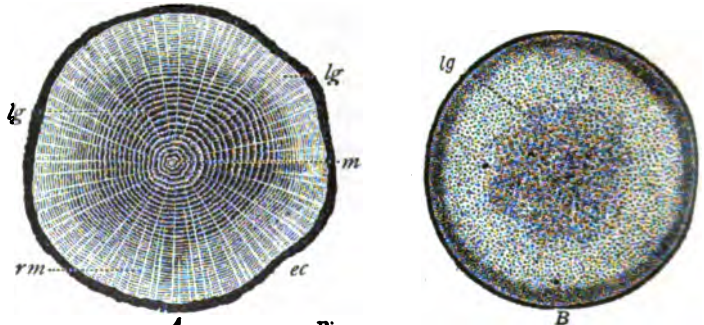

Fig. 539.

A. Cross-section of the stem of an oak tree thirty-seven years old, showing the annual rings. *rm*, the medullary rays; *m*, the pith (medulla). *B*. Cross-section of the stem of a palm tree, showing the scattered bundles.

1143. Taxonomy.—This grouping of plants into species, genera, families, etc., according to characters and relationships is *classification*, or *taxonomy*.

To take Trillium grandiflorum for example, its position in the system, if all the principal subdivisions should be included in the outline, would be indicated as follows:

Group, Angiosperms.
Class, Monocotyledones.
Order, Liliales.
Family, Liliaceæ.
Genus, Trillium.
Species, grandiflorum.

In the same way the position of the toothwort would be indicated as follows:

Group, Angiosperms.
Class, Dicotyledones.
Order, Papaverales.
Family, Cruciferæ.
Genus, Dentaria.
Species, diphylla.

But in giving the technical name of the plant only two of these names are used, the genus and species, so that for the toothwort we say *Dentaria diphylla*, and for the white wake-robin we say *Trillium grandiflorum*.

1144. Kingdom and Subkingdom.—Organic beings form altogether two kingdoms, the Animal Kingdom and the Plant Kingdom. The plant Kingdom is then divided into a number of subkingdoms as follows: 1st, Subkingdom Thallophyta, the thallus plants, including the Algæ and Fungi; 2d, Subkingdom Bryophyta, the moss-like plants, including the Liverworts and Mosses; 3d, Subkingdom Pteridophyta, the fern-like plants, including Ferns, Lycopods, Equisetum, Isoetes, etc.; 4th, Subkingdom Spermatophyta, the seed-plants, including Gymnosperms and Angiosperms. Subkingdoms are divided into groups of lower order down to the classes. So there are subclasses, subfamilies or tribes, subgenera, and even subspecies. But taking the principal taxonomic divisions from the greater to the lesser rank, the order would be as follows:

Plant Kingdom.
Subkingdom, Spermatophyta.
Group (not used in a definite sense).
Class, Gymnospermæ.
Order, Pinales.
Family, Pinaceæ.
Genus, Pinus.
Species, strobus, or, in full.
Pinus strobus, the white pine.

CHAPTER LIX.

MONOCOTYLEDONS.

Topic I: Monocotyledons with conspicuous petals and regular flowers.

ORDER LILIALES.

1145. Lesson I. The lily family (Liliaceæ).—Trillium, which we employed as a representative of the monocotyledons in the morphology of the angiosperms, serves as one type of the lily family. An exercise is added here on the "yellow adder's-tongue" for those who wish to study more than one example of the order. There is an abundance of material from the members of the family if the teacher desires to extend further the exercises on the Liliaceæ.

Yellow adder's-tongue (Erythronium americanum).

SUGGESTIONS FOR STUDY OF THE YELLOW ADDER'S-TONGUE.

1146. Entire plant.—Observe the bulb from which the flowering scape arises; the small scale-like leaves overlapping it; the two large spotted leaves on plants which have the flower. In the case of the non-flowering plants observe that there is only one large leaf. If an opportunity affords for an excursion in the woods where the plant grows, see if you can determine how the bulbs are formed at the ends of the "runners." As to depth in the soil compare the bulbs of the flowering and non-flowering plants.

Inflorescence.—The inflorescence is determinate, and consists of a single terminal nodding flower on a scape.

Flower.—Beginning with the outer whorl of members of the flower determine the number of members in each whorl, as well as their form, relation to each other, and the relation of the different sets among themselves.

Sketch a member of the calyx, corolla, and androecium. Sketch the pistil, naming the parts. Make a section of the pistil (preferably one in which the seeds are nearly mature) and determine the number of carpels united to form it. How are the number of carpels manifested in the stigma?

Construct a floral diagram to show the relation and number of the different members of the flower.

The flower of the adder's-tongue is *complete*, because it possesses all the floral sets. It is *perfect*, because it possesses both the androecium and gynoecium. It is *regular*, because all the members of the calyx, as well as those of the corolla, are of equal size.

1147. Other examples of the lily family.—The lily family is a large one. Another example is found in the "Solomon's-seal," with its elongated, perennial rootstock, the scars formed by the falling away of each annual shoot resembling a seal. The onion, smilax, asparagus, lily-of-the-valley, etc., are members of the lily family. The parts of the flower are usually in threes, though there is an exception in the genus *Unifolium*, where the parts are in twos. A remarkable exception occurs sometimes in Trillium grandiflorum, where the flower is abnormal and the parts are in twos.

Outdoor Observations on Some of the Liliaceæ.

If the study of the plant families is carried on during the spring, excursions should be made, if possible, to the fields and woods at opportune times for the purpose of studying some of the plants in their natural surroundings. The short studies given here will serve to indicate some of the observations that can be made during these excursions.

Some of the early spring flowers like trillium and erythronium are formed the previous year, and are nearly or quite mature in the autumn. The flower-bud is, of course, at this time unfolded. The stem which bears the flower is very short, so that the flower-bud is covered by leaf-mold and soft humus during the winter. If possible one should examine plants of trillium at intervals of three or four weeks during the spring, summer, and autumn. The young flower begins to form in June and July, and by autumn

Fig. 540.
Trillium grandiflorum. (From photograph by the author.)

its parts are all formed. Sometimes in places well exposed to the sun the pollen is already developed in the autumn, while in other cases it is formed during warm days in the winter or in early spring, always before the flower opens above ground. In connection with these studies one should consult Parts III and IV. Relation of Plants to Environment, Ecology.

Topic II: Monocotyledons with a glume subtending the flower (Glumifloræ).

ORDER GRAMINALES.

1148. Lesson II. Grass family (Gramineæ). Oat.—As a representative of the grass family (gramineæ) one may take the

Fig. 541. Spikelet of oat showing two glumes.

Fig. 542. One glume removed showing fertile flower.

Fig. 543. Flower opened showing two palets, three stamens, and two lodicules at base of pistil.

Fig. 544. Section showing ground plan of flower. *a*, axis.

Fig. 545. Flower of oat, showing the upper palet behind, and the two lodicules in front.

oat plant, which is widely cultivated, and also can be grown readily in gardens, or perhaps in small quantities in greenhouses in order to have material in a fresh condition for study. Or we may have recourse to material preserved in alcohol for the dissection of the flower. The plants grow usually in stools; the

stem is cylindrical, and marked by distinct nodes, as in the corn plant. The leaves possess a sheath and blade. The flowers form a loose head of a type known as a panicle. Each little cluster as shown in fig. 541 is a spikelet, and consists usually here of one or two fertile flowers below and one or two undeveloped flowers above. We see that there are several series of overlapping scales. The two lower ones are "glumes," and because they bear no flower in their axils are empty glumes. Within these empty glumes and a little higher on the axis of the spike is seen a boat-shaped body, formed of a scale, the margins of which are folded around the flowers within, and the edges inrolled in a peculiar manner when mature. From the back of this glume is usually borne an awn. If we carefully remove this scale, the "flower glume," we find that there is another scale on the opposite (inner) side, and much smaller. This is the "palet."

1149. Next above this we have the flower, and the most prominent part of the flower, as we see, is the short pistil with the two plume-like styles, and the three stamens at fig. 543. But if we are careful in the dissection of the parts we shall see, on looking close below the pistil on the side of the flowering glume, that there are two minute scales (fig. 545). These are what are termed the *lodicules*, considered by some to be merely bracts, by others to represent a perianth, that is two of the sepals, the third sepal having entirely aborted. Rudiments of this third sepal are present in some of the gramineæ.

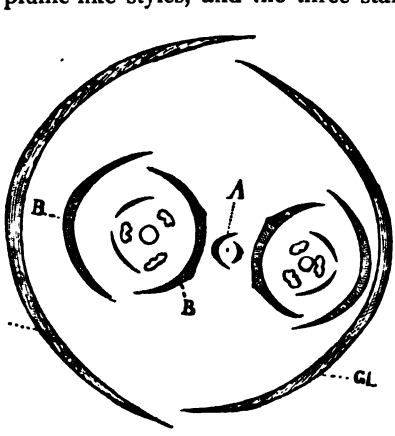

Fig. 546.
Diagram of oat spikelet. *Gl*, glumes; *B*, palets; *A*, abortive flower.

1150. To the gramineæ belong also the wheat, barley, corn

the grasses, etc. The gramineæ, while belonging to the class monocotyledons, are less closely allied to the other families of the class than these families are to each other. For this reason they are regarded as a very natural group.

SUGGESTIONS FOR THE STUDY OF THE CORN.

1151. The corn (Zea mays).—The corn or wheat plant may be studied as an alternate for the oat plant.

The corn plant.—Describe the entire plant; the underground roots; the aerial roots in the case of mature plants; the nodes and internodes of the stem; the leaves. Determine the arrangement of the leaves; the parts of the leaf (blade, sheath; is there a ligule, a membranous appendage at the junction of the blade and sheath, present?). Sketch a leaf showing all the parts. Sketch an entire plant to show details. (See Chapter X for structure of seed, and germination.)

The staminate inflorescence (the "tassel") forms a terminal panicle on the stem, composed of several spikes which branch from the axis. Note the numerous spikelets on each spike. Determine the number of spikelets at each joint of the rachis (axis of the spike). Separate the parts of a spikelet, and sketch to show the parts of a flower as in the oat shown in figs. 545 and 546. Make a diagram to show the ground plan of the flower.

The pistillate inflorescence (the ear of corn). This occurs in the axil of the leaves at the joints of the stem. The spikes of each leaf-axil are grown together into a thickened axis ("cob"), forming the "ear" of corn which is covered by the numerous leaf-like bracts ("husks") arising from its base. The styles, each attached to the ovary, emerge from between the ends of the bracts in a silky tuft.

Sketch a cross-section of an ear showing the arrangement of the ovaries or grains of corn on the axis (cob). Remove some of the ovules (or grains of mature corn) and note the scale-like bracts at the base of each. (In some varieties of corn these scale-like bracts are larger and enclose the grain, as in the oat or barley.

Material.—Entire corn plants at maturity (may be preserved dry); young "ears" of corn at time the silk is formed (may be preserved in alcohol or dry); the "tassel," at the time of flowering (some of the material should be preserved in alcohol or formalin); ripe ears of corn with the "husks" (dry).

1152. Lesson III. The sedge family (Cyperaceæ). Carex.—As an example of the sedges a species of the genus carex may be studied. If plants

of Carex lupulina are taken from the soil carefully, we find that there is an underground stem or rootstock which each year grows a few inches, forms new attachments by roots to the soil, and thus the plant may spread from year to year. This underground stem, as seen, has only scaly leaves. The upright stems reach a height of two to three feet, and are prominently three-angled, as are most of the species of this large genus. The leaves are three-ranked, and consist of a long sheathing base and a long narrow blade. The flowers, as we see, are

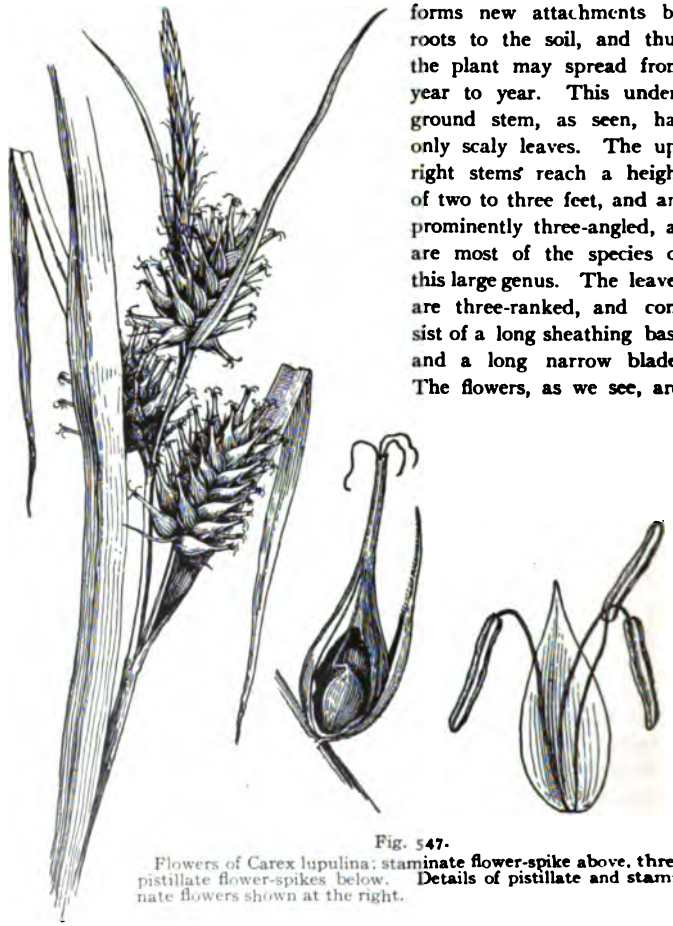

Fig. 547.

Flowers of Carex lupulina; staminate flower-spike above, three pistillate flower-spikes below. Details of pistillate and staminate flowers shown at the right.

clustered at the end of the stem, or sometimes additional ones arise in the axils of the leaves lower down on the stem. The staminate flowers form a slender, short spike, terminating the stem, while the pistillate flowers form several spikes arising as branches. The flowers are very much reduced here, and each of the pistillate flowers consists of one pistil which is surrounded by a flask-shaped scale, the *perigynium*. These perigynia can be distinctly seen upon the spike. At the apex of the perigynia the

three styles emerge. Just below each perigynium is a slender scale, the primary bract, from the axil of which the pistillate flower arises.

Fig. 548.
Two carex flowers.

Fig. 549.
Pistil of carex.

Fig. 550.
Section of pistil.

For the study of the flowers one must select material at the time the male flowers are in bloom. In fig. 551 is represented a portion of the staminate spike of Carex laxiflora. As seen here each staminate flower consists of three stamens. These stamens arise in the axil of a bract. Figure 548 represents a portion of the pistillate spike of the same species at the time of flowering The fact that the parts, or members, of the flower are in threes suggests that there may be some relationship between the carex and the monocotyledons already studied, even though each flower has become so reduced in the number of its members.

Fig. 551.
Two male flowers of Carex laxiflora.

1153. In the bulrush (scirpus), another genus of this family, the flowers are perfect and complete (having all parts of the flower), with the parts in threes or some multiple of three. Here there is a more obvious resemblance to the monocotyledenous type.

CHAPTER LX.

MONOCOTYLEDONS CONCLUDED.

Topic III. Monocotyledons with Flowers on a Spadix.

ORDER ARALES.

1154. Lesson IV. The arum family (Araceæ).—This family is well represented by several plants. The skunk's cabbage (Spathyema fœtida) illustrated in figs. 458–460 is an interesting example. The flowers are closely crowded around a thick stem axis. Such an arrangement of flowers forms a "*spadix*." The spadix is partly enclosed in a large bract, the "*spathe*." The sepals and stamens are four in number, and the pistil has a four-angled style. The coralla is wanting. (See Chapter XLIII for farther characters of the flower.)

1155. The "jack-in-the-pulpit," also called "Indian turnip" (Arisæma triphyllum), shown in fig. 461, the water-arum (Calla palustris), and the sweet flag (Acorus calamus) are members of this family, as also are the callas and caladiums grown in conservatories. The parts of several of the species of this family, especially the corm of the Indian turnip, are very acrid to the taste. The floral parts are more or less reduced.

DESCRIPTION OF THE INDIAN TURNIP.

Indian turnip.—The "Indian turnip," or "jack-in-the-pulpit" (Arisæma triphyllum), loves the cool, shady, rich, alluvial soil

of low grounds, or along streams, or on moist hillsides. A group of the jacks is shown in fig. 461 as they occur in the rich soil on dripping rocks in one of our glens. The thin, strap-shaped spathe, unfolded at its base, bends gracefully over the spadix, the sterile end of which stands solitary in the pulpit thus formed. The flowers are very much reduced, i.e., the number of members in the sets is reduced so that they do not appear in threes as in the typical monocotyledons. Some of the members are also often reduced in size or are rudimentary. The plants are "dimorphic" usually.

Female plants.—The large plants usually bear the pistillate flowers, which are clustered around the base of the spadix, each flower consisting of a single pistil, oval in form, terminating in a brush-like stigma. The stigma consists of numerous spreading, delicate hairs. The open cavity of the short style is hairy also, and a brush of hairs extends into the cavity of the ovary. Into this brush of internal hairs the necks of the several ovules crowd their way to the base of the style near its opening. Even when the stigma is not pollinated the ovary continues to grow in size, and the stigmatic brush remains fresh for a long time.

Male plants.—Excepting some of the intermediate sizes, one can usually select on sight the male and female plants. The smaller ones which have a spathe are nearly all male and bear a single leaf, though a few have two leaves. The male flowers are also clustered at the base of the spadix, and are very much reduced. Each flower consists only of stamens, and singularly the stamens of each flower are joined into one compound stamen, the anther-sacs forming rounded lobes at the end of the short consolidated filaments.

The female plants require more food than the male plants.—In some plants both male and female flowers occur on a single spadix, the lower flowers being female, while the upper ones are male. The larger plants are nearly all female, and many, though not all, bear two leaves. In this dimorphism of the plant there is a division of labor apportioned to the destiny and needs of each, and in direct correspondence with the capacity

to supply nutriment. The staminate flowers, being short-lived, need a comparatively small amount of nutriment, and after the escape of the pollen (dehiscence of the anthers) the spathe dies, while the leaf remains green to assimilate food for growth of the fleshy short stem (corm), where also is stored nutriment for the growth in the autumn and spring when the leaf is dead. The female plants have more work to do in providing for the growth of the embryo and seed, in addition to the growth of the corm and next season's flower. The smaller female plants thus sometimes so exhaust themselves in seed-bearing that the corm becomes small, and the following season the plant is reduced to a male one.

Growth and death of the corm.—The new roots each year arise from the upper part of the corm. The stored substances in the base of the corm are used in the early season's growth, and the old tissue sloughs off as the new corm is formed above upon its remains.

Suggestions for Study of the Indian Turnip.

Staminate plants (sometimes called male plants).—Sketch an entire plant showing the corm (the thickened perennial stem), the annual shoot with leaves and spathe. Cut away one side of the spathe to expose the long compact cluster (spadix) of staminate flowers within. Sketch the spadix, showing the mass of stamens as well as the sterile part of the shoot above. Dissect off from the axis several of the stamens. Note that the filament is very short, and that the anther is irregularly lobed.

The pistillate plants (sometimes called female plants).—Compare with the staminate plant. How many leaves are there? Is the number of leaves constant on all the pistillate plants? Cut away one side of the spathe and expose the spadix of pistillate flowers. Sketch. Observe that each flower consists of a single flask-shaped pistil, and that these are packed closely together. Note the delicate brush-like stigma. Search for plants which show both stamens and pistils on the same spadix. Where both kinds of flowers are present on the same spadix, on what part of the spadix does each kind appear? On the corm of different plants search for lateral buds, which are young plants. Observe that they usually arise on directly opposite sides of the corm; that they easily become freed from the old corms; that they are young corms. Do they arise in the axils of the leaves or scale leaves which have fallen away?

Cut off a portion of the corm. Do not eat any portion, but touch the tongue to the cut surface. The flesh of the corm is very acrid.

Material.—Freshly collected plants should be used, the entire plant; small ones as well as large ones.

1156. Related to the arum family are the "duckweeds." Among the members of this family are the most diminutive of the flowering plants, as well as the most reduced floral structures. (For description and illustration of three of these duckweeds, see Chapter III.)

Other related families are the cat-tails and palms. In the latter the spathe and spadix are of enormous size. The cocoanut is the fruit of the cocoanut palm.

Topic IV: Monocotyledons with large petals and irregular flowers.

ORDER ORCHIDALES.

1157. Lesson V. The orchid family (Orchidaceæ).—In the orchids are found the most striking departures from the arrangement of the flower which we found in the simpler monocotyledons. An example of this is seen in the lady-slipper (Cypripedium, shown in fig. 467). The ovary appears to be below the calyx and corolla. This is brought about by the adhesion of the lower part of the calyx to the wall of the ovary. The ovary then is *inferior*, while the calyx and corolla are *epigynous*. The stamens are united with the style by adhesion, two lateral perfect ones and one upper imperfect one. The stamens are thus *gynandrous*. The sepals and petals are each three in number. One of the petals, the "slipper," is large, nearly horizontal, and forms the "lip" or "labellum" of the orchid flower. The labellum is the platform or landing-place for the insect in cross-pollination (see Chapter XLIII, Pollination). Above

Fig. 552.

Flower of an orchid (Epipactis), the inferior ovary twisted as in all orchids so as to bring the upper part of the flower below.

the labellum stands one of the sepals more showy than the others, the "banner." The two lateral "strings" of the slipper are the two other petals. The stamens are still more reduced in some other genera, while in several tropical orchids three normal stamens are present.

There are thus four striking modifications of the orchid flower: 1st, the flower is irregular (the parts of a set are different in size and shape); 2d, adnation of all parts with the pistil; 3d, reduction and suppression of the stamens; 4th, the ovary is twisted half-way around so that the posterior

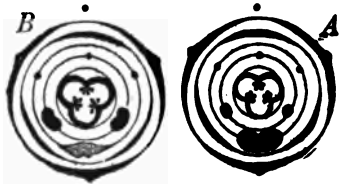

Fig. 553.
Diagrams of orchid flowers. *A*, the usual type; *B*, of cypripedium. (Vines.)

Fig. 554.
Diagram of flower of canna.

side of the flower becomes anterior. Floral diagrams in fig. 553 show the position of the stamens in two distinct types. The number of orchid species is very large, and the majority are found in tropical countries.

Related to the orchids are the iris family, in which the stigma is expanded into the form of a petal, and the canna family. In the canna the flower is irregular (see figs. 470, 471) and the ovary is inferior. (See Chapter XLIII, on pollination, for description of the canna flower.)

CHAPTER LXI.

DICOTYLEDONS.

Topic V: Dicotyledons with distinct petals, flowers in catkins, or aments; often degenerate.

ORDER SALICALES.

1158. Lesson VI. The willow family (Salicaceæ).—The willows represent a very interesting group of plants in which the flowers are greatly reduced. The flowers are crowded on a more or less elongated axis forming a *catkin*, or *ament*. The ament is characteristic of several other families also. The willows are dicœcious, the male and female catkins being borne on different plants. The catkins appear like great masses of either stamens or pistils. But if we dissect off several of the flowers from the axis, we find that there are many flowers, each one subtended by a small bract. In the male or "sterile" catkins the flower consists of two to eight stamens, while in the female or "fertile" catkins the flower consists of a single pistil. The poplars and willows make up the willow family.

SUGGESTIONS FOR STUDY OF THE WILLOW.

1159. The willow (Salix discolor).

The leafy shoot.—Determine the arrangement of the leaves of the willow; sketch a leaf showing its form, the character of the margin and of the venation. If different willows are at hand, compare the color of the twigs, as well as the character of the twigs as to brittleness or litheness.

The inflorescence.—What is the kind of inflorescence? Are both kinds of flowers borne on the same ament (catkin) or on different aments?

The staminate catkins.—Determine what constitutes a flower by dissecting some of them off from the axis of the catkin. What parts of the

flower are present? How many stamens in a flower? If a hand lens is convenient, use it in making out the form of the parts. Sketch a flower in its position on the axis of the catkin, showing also the bract at the base of the flower. Describe the character of the bract as seen under the lens.

The pistillate catkin.—What parts of the flower are present? Compare with the staminate flower. Sketch a pistillate flower with the subtending

Fig. 555.
Spray of willow leaves, pistillate and staminate catkins (Salix discolor).

bract to show the form of the ovary, with the divided stigma. Is the pistil sessile or stalked? How many carpels make up the pistil? Is there a small gland (nectary) present near the base of the ovary which represents the perianth? Is there a nectary on the staminate flower?

The fruit.—Examine ripe pods of the willow. Determine what parts of the flower unite to form the fruit. What difference between a fruit and seed in the willow? What means is provided for the dissemination of the seeds?

Field observations on the willows.—At what time do the catkins of the willow appear? Do they flower before the leaves appear? At time of flowering note the character and abundance of the pollen from the stamens. Is it in the form of "dust," or is it adhesive? How are the willows pollinated? Do insects visit the willow flower? Are willows easily propagated by shoots? What happens if a willow branch is stuck into damp soils; when it is left in the water for some time?

Material.—Shoots of the willow, some with leaves, some with the catkins (the two kinds of catkins occur on different plants). If material cannot be obtained fresh when wanted for study, the leafy shoots may be preserved dry, and the catkins in alcohol or formalin, or dry. Ripe fruit should also be at hand; this may be preserved dry.

ORDER FAGALES.

1160. Lesson VII. The oak family (Cupuliferæ).—A small branch of the red oak (Quercus rubra) is illustrated in fig. 556. This is one of the rarer oaks, and is difficult for the beginner to

Fig. 556.
Spray of oak leaves and flowers. Below at right is staminate flower, at left pistillate flower.

distinguish from the scarlet oak. The white oak is perhaps in some localities a more convenient species to study. But for the

general description here the red oak will serve the purpose. Just as the leaves are expanding in the spring, the delicate sprays of pendulous male catkins form beautiful objects. The petals are wanting in the flower, and the sepals form a united calyx, with several lobes, that is, the parts of the calyx are *co-*

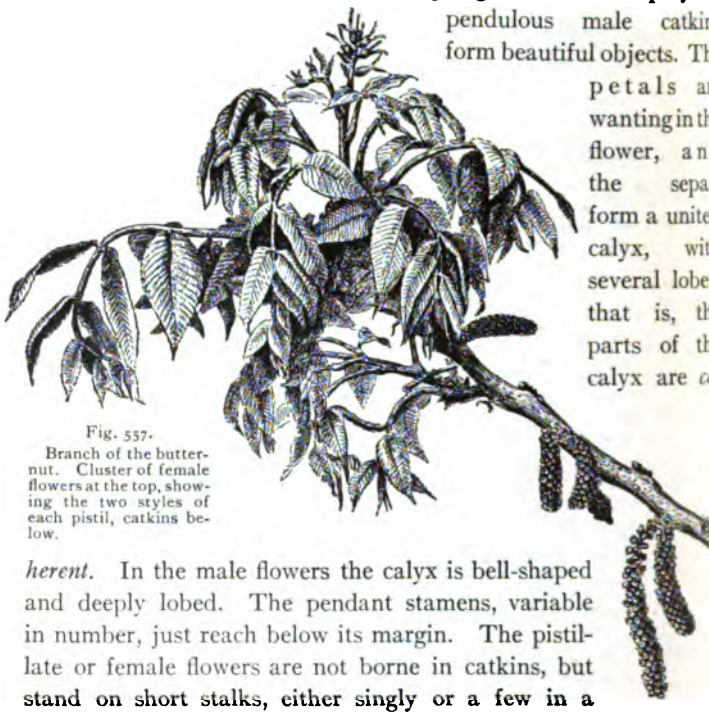

Fig. 557.
Branch of the butternut. Cluster of female flowers at the top, showing the two styles of each pistil, catkins below.

herent. In the male flowers the calyx is bell-shaped and deeply lobed. The pendant stamens, variable in number, just reach below its margin. The pistillate or female flowers are not borne in catkins, but stand on short stalks, either singly or a few in a cluster. The calyx here is urn-shaped with short lobes. The ovary consists of three united (coherent) carpels, and there are three stigmas. Only one seed is developed in the ovary, and the fruit is an acorn. The numerous scales at the base of the ovary form a scaly involucre, the *cup*.

The beech, chestnut, and oak are members of the oak family.

The following additional families among the ament-bearers are represented in this country: the birch family (birch, alder), the hazelnut family (hazelnut, hornbeam, etc.), walnut family (hickory, walnut), and the sweet-gale family (myrica).

Suggestions for Study of the Oak.

1161. The oak.—(The white oak or any common one in the neighborhood.)

The leaves.—Determine the arrangement of the leaves on the shoot. Sketch a leaf showing the form, outline, and venation. Compare the young leaves with the old ones as to texture, surface characters, etc.

The inflorescence.—What is the kind of inflorescence? Are both kinds of flowers in the same inflorescence or in different inflorescences?

The staminate inflorescence.—Note the cluster of staminate aments. Determine a single flower and sketch it to show the parts. What parts of the flower are present? Determine the number of parts of each set present.

The pistillate inflorescence.—How does it differ from the staminate inflorescence? Sketch a pistillate flower, showing the parts. What parts of the flower are present?

The fruit (an acorn with the cup).—Sketch an acorn in the "cup." What is the homology of the cup—i.e., to what part or series of members of the plant does it belong? Could the pistillate flower of the ancestors of the oak have been in the form of aments, and if so, could the cup of the acorn represent the degraded and consolidated ament? If so, what part of the ament would now be represented in the cup? (It has also been suggested that the scales of the involucre which makes up the cup are adventitious growths accompanying the development of the fruit.) See Chapter XLIV.

(If the acorn has not been studied under the paragraph dealing with seeds and fruits, and if there is time now, remove the wall of the acorn and determine the parts of the embryo. Are any parts of the embryo green while still enclosed within the acorn?)

Field observations on the oaks.—Compare the time of appearance of the flowers and leaves of the oak. What about the abundance of the pollen? How are the oaks pollinated? The ament-bearing plants are usually wind-pollinated, and for this reason there is an abundance of pollen, and always in the form of dust. Is there an exception to this general rule? How long after the flowers are formed before the acorn is ripe?

If there is time during excursions, note other ament-bearing plants.

Material.—Mature leaves, leafy shoots, sprays of the flowers, both pistillate and staminate; fruit (the acorn in the cups).

CHAPTER LXII.

DICOTYLEDONS CONTINUED.

Topic VI: Dicotyledons with distinct petals and hypogynous flowers.

ORDER URTICALES.

1162. Lesson VIII. The elm family (Ulmaceæ).—The elm tree belongs to this family. The leaves of our American elm (Ulmus americana) are ovate, pointed, deeply serrate, and with

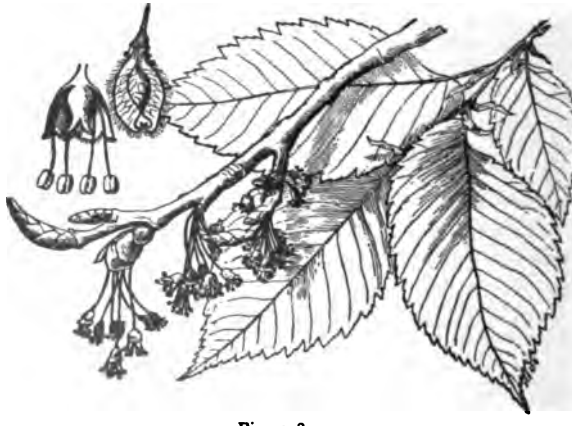

Fig. 558.

Spray of leaves and flowers of the American elm; at the left above is section of flower next is winged seed (a samara).

an oblique base as shown in fig. 558. The narrow stipules which are present when the leaves first come from the bud soon fall away. The flowers are in lateral clusters, which arise from

the axils of the leaves, and appear in the spring before the leaves. They hang by long pedicels, and the petals are absent. The calyx is bell-shaped, and 4–9-cleft on the margin. The stamens vary also in number in about the same proportion. A section of the flower in fig. 558 shows the arrangement of the parts, the ovary in the center. The ovary has either one or two locules, and two styles. The mature fruit has one locule, and is margined with two winged expansions as shown in the figure. This kind of a seed is a *samara*.

Suggestions for Study of the Elm.

1163. The elm (Ulmus americana).

Leaves.—What is the arrangement of the leaves on the shoot? Sketch a leaf showing its attachment to the shoot, and the relation of the stipules; note how easily the stipules fall away.

The inflorescence.—Describe the inflorescence; a single flower; sketch a single flower in the position in which it stands on the tree. Cut away the floral envelope on one side; determine the number of stamens; the number of pistils; are the pistils single or compound? Of how many carpels is it composed? Sketch a flower with the front part of the envelope and the front stamens removed. What part of the floral envelope is present? What is its character and form? What are the relations of the sets of the flower to each other? In time of appearance how do the flowers compare with the leaves?

Describe the mature fruit; how many seed are present? What parts of the flower are united in the fruit? What is the fruit called?

Material.—Spray of leaves and flowers; it may be necessary to collect them at different times. Leafy shoots should be collected while some of the leaves are still young in order to preserve some with the stipules, and they may be preserved dry and pressed. Fruits collected at the time of maturity may be preserved dry.

ORDER RANALES.

1164. Lesson IX. The crowfoot family (Ranunculaceæ).—The marsh-marigold (Caltha palustris) is a member of this family. The leaves are heart-shaped or kidney-shaped, and the edge is crenate. The bright golden-yellow flowers have a single whorl of petal-like envelopes, and according to custom in such cases they are called sepals. The number is not definite, varying from

five to nine usually. The stamens are more numerous, as is the general rule in the members of the family, but the number of the pistils is small. Each one is separate, and forms a little pod when the seed is ripe. The marsh-marigold, as its name implies, occurs in marshy or wet places and along the muddy banks of streams. It is one of the common flowers in April and May.

Fig. 559.
Caltha palustris, marsh-marigold.

Fig. 560.
Diagram of marsh-marigold flower.

Many of the crowfoots or buttercups (Ranunculus) with bright yellow flowers grow in similar situations. The "wood anemone" (Anemone), small plants with white flowers, and the rue-anemone (Anemonella), which resembles it, both flower in woods in early spring. The common virgin's-bower (Clematis virginiana) occurs along streams or on hillsides, climbing over shrubs or fences. The vine is somewhat woody. The leaves are opposite, petioled, and are composed of three leaflets, which are ovate, three-lobed, and usually strongly toothed, and somewhat heart-shaped at the base. The flower-clusters are borne in the axils of the leaves, and therefore may also be opposite. The clusters are much branched, forming a convex mass of beautiful whitish flowers. The sepals are colored and the petals may be absent,

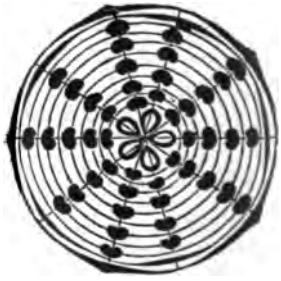

Fig. 561.
Diagram of aquilegia flower. (Vines.)

or are very small. The stamens are numerous, as in the members of the crowfoot family. The pistils are also numerous, and the achenes in fruit are tipped with the long plumose style, which aids them in floating in the air.

Some of the characters of the Ranunculaceæ we recognize to be the following:

Fig. 562.
Clematis virginiana; below at right are pistillate and staminate flowers.

Fig. 563.
Isopyrum biternatum.

The plants are mostly herbs, the petals are separate, and when the corolla is absent the sepals are colored like a corolla. The stamens are numerous, and the pistils are either numerous or few, but they are always separate from each other, that is, they are not fused into a single pistil (though sometimes there is but one pistil). All the parts of the flower are separate from each other, and make up successive whorls, the pistils terminating the series. When the seeds are ripe the fruit is formed, and may be in the form of a pod, or achene, or in the form of a berry, as in the baneberry (Actæa).

Suggestions for Study of the Buttercup.

1165. The buttercup.—If preferred, a species of buttercup may be studied instead of the marsh-marigold, but a comparison with the latter is desirable.

The entire plant.—Describe form and habit of the plant; the character of the stem; branching; the form and arrangement of the leaves; the character of the roots (these characters will depend on the species).

The inflorescence.—What kind of inflorescence? What parts of the flower are present? Describe the color and form of members of the different sets of the flower. Determine the number of members in each set (approximately if not accurately).

Sketch a sepal, a petal (is a nectar-gland present?), a stamen, and a pistil, noting carefully the characters of each.

Do the stamens all ripen their pollen at the same time? Is there any advantage as regards the time of ripening of the stamens?

What is the relation of the members of a set among themselves? What is the relation of the sets to each other?

Is the flower perfect or imperfect, complete or incomplete? Is it regular or irregular; hypogynous, perigynous, or epigynous? Are the parts of the flower free and distinct, or adherent, or coherent?

If fruit is present, determine the number of seed in a ripe fruit, and also what parts of the flower make up the fruit.

If there is time, a comparison of the flowers, fruit, and leaves of different species of the Ranunculus will be found interesting, especially species from dry and wet ground, as well as some of the species which grow in the water.

Construct the formula for the buttercup flower; also construct the floral diagram.

Material.—Entire plants, some flowering stems with flowers, some with fruit. Fresh material when possible.

ORDER PAPAVERALES.

1166. Lesson X. The mustard family (Cruciferæ).—This is well represented by the toothwort (Dentaria), which we studied in a former chapter. The flowers are regular, and the parts are usually in twos (dimerous) or in fours (tetramerous). (If the toothwort has been studied, the shepherd's-purse may be omitted.)

Suggestions for Study of the Shepherd's-purse.

1167. The shepherd's-purse (Capsella bursa-pastoris).—If it is desired to study a species besides the toothwort, the shepherd's-purse will answer. It is a common and widely distributed species, found in waste places and in fields.

The entire plant.—Note and describe the habit and character of the plant, i.e., the size, character of branching, character of the root, position and arrangement of the leaves. Compare the "radicle" (lower) leaves with the "cauline" (stem) leaves as to form and insertion. The radicle leaves are more or less deeply lobed or pinnatifid (pinnately cut), while the stem leaves are slender, lanceolate, toothed, and often auricled (with little ears) at the base.

The inflorescence.—What is the kind of inflorescence? Determine the parts of the flower present, as well as the number and arrangement of the members of the flower. What figure which suggests the name of the family to which the shepherd's-purse and the toothwort belong, do the petals make in the flower?

The fruit.—What parts of the flower are united in the fruit? Compare the plant with the toothwort.

Construct the floral diagram of the toothwort or shepherd's-purse, or of other cruciferous plant studied.

Material.—Entire plants with flowers and fruit. The plant occurs from early spring to autumn, and can be usually obtained in a fresh condition when wanted.

Fig. 564.
Branch of cranesbill (Geranium maculatum), showing upper leaves, flowers, and pods.

ORDER GERANIALES.

1168. Lesson XI. The geranium family (Geraniaceæ).—The wild cranesbill has a perennial underground rootstock. From this in the spring arises the branched, hairy stem. The leaves are deeply parted into about five wedge-shaped lobes, which are again cut. The peduncles bear several purple flowers (fig. 564). The floral formula is as follows: Ca_5, Co_5, A_{10}, G_5. The wood-sorrel (Oxalis), the balsam or jewelweed (Impatiens), sometimes called "touch-me-not," are members of the same family.

CHAPTER LXIII.

DICOTYLEDONS CONTINUED.

Topic VII: Dicotyledons with distinct petals and perigynous or epigynous flowers. Many trees and shrubs.

ORDER ROSALES.

1169. Lesson XII.—The rose-like flowers are an interesting and important group. In all the members the receptacle (the end of the stem which bears the parts of the flower) is an important part of the flower. It is most often widened, and either cup-shaped or urn-shaped, or the center is elevated. The carpels are borne in the center in the depression, or on the elevated central part where the receptacle takes on this form. The calyx, corolla, and the stamens are usually borne on the margin of the widened receptacle, and where this is on the margin of a cup-shaped or urn-shaped receptacle they are said to be *perigynous*, that is, around the gynœcium. The calyx and corolla are usually in fives. There are three families, as follows.

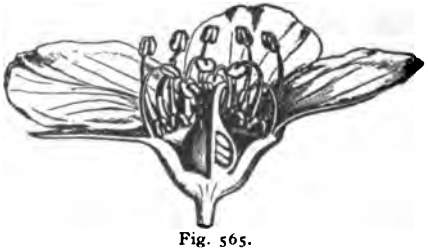

Fig. 565.
Perigynous flower of spiræa (S. lanceolata). (From Warming.)

1170. The rose family (Rosaceæ).—In this family there are five types, represented by the following plants and illustrations: 1st. In spiræa (fig. 565) the receptacle is cup-shaped. There are five carpels, united at the base, but free at the ends. 2d. In the strawberry the receptacle is conic and bears the carpels (fig. 566). The conic receptacle becomes the fleshy fruit, with the seeds in little pits over the surface. 3d. The raspberries, blackberries, etc., represented here by the flowering raspberry (Rubus odoratus), fig. 567. 4th. This is represented by the roses. The receptacle is urn-shaped and constricted toward the upper portion, with the carpels enclosed in the base (fig. 568). 5th. Here the receptacle is cup-shaped or bell-shaped and nearly closed at the mouth as in the agrimony.

Fig. 566.
Flower of Fragaria vesca with columnar receptacle. (From Warming.)

Fig. 567.
Flowering raspberry (Rubus odoratus).

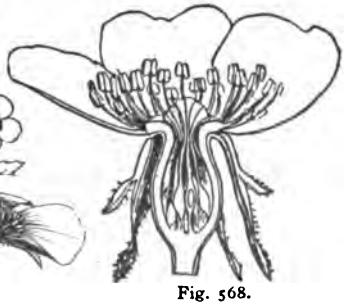

Fig. 568.
Perigynous flower of Rosa, with contracted receptacle. (From Warming.)

SUGGESTIONS FOR STUDY OF THE STRAWBERRY.

1171. The strawberry (Fragaria vesca).

Describe the appearance of the entire plant. What different stems are there? What purpose does each kind of stem serve? Sketch and describe a leaf.

The inflorescence.—What is the kind of inflorescence?

The flower.—Determine the parts of the flower present. Describe each set of members of the flower, naming the kind of calyx and corolla. Are the sets of members free? Are the members of each set distinct? To take the flower as a whole in its young condition (just opening), what is the relation as regards position and elevation of the different sets to each other? Is the flower perigynous or hypogynous?

What is the end of the stem called to which the parts of the flower are attached?

Do all the flowers of the strawberry form fruit? When you have determined this, determine the reason if you can.

The fruit.—What parts of the flower are united to form the fruit? What is such a fruit called? What part of the flower forms the fleshy part of the fruit? What parts of the flower are united in the seed? What is such a seed called?

How does seed distribution come about in such plants as the strawberry? How are strawberry plants usually propagated?

Material.—Entire plants with runners; flowers; fruit.

1172. Lesson XIII. Plums, cherries, pears, apples. The almond or plum family (Drupaceæ).—The members of this family are trees or shrubs. The common choke-cherry (fig. 569) will serve to represent one of the types. The flowers of this species are borne in racemes. The receptacle is cup-shaped. Only one seed in the single carpel (sometimes two carpels) matures as the calyx falls away. The outer portions of the ovary become the fleshy fruit, while the inner portion becomes the hard stone with the seed in the center. Such a fruit is a *drupe*.

The floral formula for this family is as follows:

$$Ca5, Co5, A15\text{–}20 \text{ or } 30, G1.$$

The apple family (Pomaceæ).—This family is represented by the apples, pears, quinces, June-berries, hawthorns, etc.

The members are trees or shrubs. The receptacle is somewhat cup-shaped and hollow. The perianth and stamens are at first perigynous, but become epigynous (upon the gynœcium) by the fusion of the receptacle with the carpels. The floral

Fig. 569.
Choke-cherry (Prunus virginiana). Leaves, flower-raceme, and section of flower at right.

formula is thus Ca5,Co5,A10–5–5 or 10–10–5,G1–5. The carpels are united, but the styles are free. In fruit the united carpels fuse more or less with the receptacle.

Suggestions for Study of the Apple.

1173. The apple (Pyrus malus).

Leaves.—Determine the arrangement of the leaves on the shoot; sketch a leaf.

The inflorescence.—Determine the kind of inflorescence.

The flower.—Study several flowers to compare the variation in the

number of the parts or members of the flower. What parts of the flower are present?

Make a long section of the flower and sketch showing the parts and their relation to each other

Fig. 570.
Flower of pear. (After Warming.)

Determine the number of members in each set; the relation of the members of a set to each other; the relation of the sets among themselves. Give the names which are applied to these relations.

The fruit.—What parts of the flower are united in the fruit? Make longitudinal and cross sections of an apple, name the parts and show from which part of the flower each part of the fruit comes. What is the fruit of an apple-tree called?

Material.—Spray of leaves and flowers; mature fruit.

1174. Lesson XIV. The pea family (Papilionaceæ).—This family is well represented by the common pea. The flower is

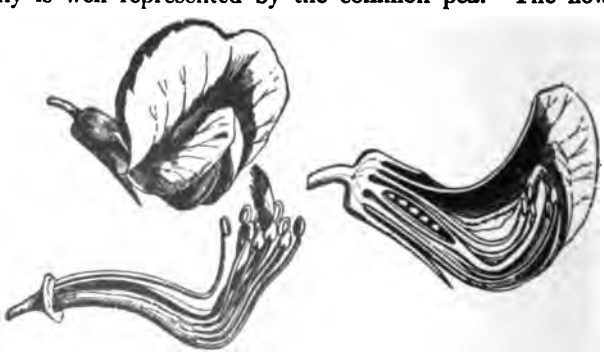

Fig. 571.
Details of pea flower; section of flower, perianth removed to show the diadelphous stamens, one single one, and nine in the other group. (From Warming.)

butterfly-like or *papilionaceous*, and the showy part is made up of the five petals. The petals have received distinct names

here because of the position and form in the flower. At fig. 572 the petals are separated and shown in their corresponding positions, and the names are there given. The flower is irregular and the parts are in fives, except the carpel, which is single. The calyx is gamosepalous (coherent), the corolla polypetalous (distinct). The ten stamens are in two groups, one separate stamen and nine united; they are thus diadelphous (two brotherhoods). The fruit forms a pod or legume, and at maturity splits along both edges.

Fig. 572.
Corolla of pea. *S*, standard; *W*, wings; *K*, two petals forming keel.

There are three families in the legume-bearing plants: 1st, including the locusts, cassias, etc.; 2d, the pea family, including peas, beans, clovers, ground-nuts, or peanuts, vetches, desmodium, etc.; 3d, including the sensitive plants like mimosa.

Suggestions for Study of the Pea.

1175. The pea (Pisum sativum).

The entire plant.—Describe the entire plant, the branching, the means for support (compare different cultivated varieties in respect to size, habit, and means for support if practicable).

The leaf.—Sketch a leaf; name the different parts; what kind of a leaf is it? Does the leaf serve any purpose for the mechanical support of the plant? How?

The inflorescence.—What is the kind of inflorescence?

The flower.—Is it regular or irregular?

The calyx.—Describe the calyx. How many sepals are indicated? Are the sepals distinct or coherent? What name is applied to this kind of a calyx?

The corolla.—What are the relations of the petals to each other? What term is applied to indicate this relation? Sketch a flower, and name the different parts of the corolla; what name is given to such a flower?

The stamens (remove the corolla).—How many stamens are there? What is their relation to each other? What terms are used to indicate such a relation of stamens of each other?

The pistil.—How many carpels in the pistil? Is it simple or compound? Sketch a young pistil, naming the parts.

The fruit.—What parts of the flower are united in the fruit? Describe the fruit. What is such a fruit called? How are the seeds freed? What is the difference between a fruit and a seed in the pea plant?

The clover (Trifolium).—If it is desired to study a clover, study one in a similar way.

Nitrogen gatherers.—The pea, clovers, etc., are sometimes called nitrogen gatherers (see Chapter IX). During an excursion let the pupils dig up different leguminous plants, like the pea, clover, lupine, etc., and search

Fig. 573.
Spray of leaves and flowers of the sugar-maple.

for the "tubercles" on their roots, comparing the form of the tubercles on the different kinds of plants.

Pollination.—If the flowers of Cytisus from a conservatory are at hand, attempt to press the point of a pencil in between the parts of the keel in the case of flowers where these parts are still closed; describe the action of the stamens in throwing the pollen. How could cross-pollination be brought about in such a flower by the visits of insects?

Study the common lupine (Lupinus perennis) in the same way. Study the pea flower with the same object in view; has the pea flower become adapted to self-pollination?

Material.—Sprays of leaves and flowers; fruit. Material can usually be obtained fresh early in the spring and for some time later.

ORDER SAPINDALES.

1176. Lesson XV. The maple family (Aceraceæ).—Fig. 573 represents a spray of the leaves and flowers of the sugar-maple (Acer saccharinum), a large and handsome tree. The leaves are opposite, somewhat ovate and heart-shaped, with three to five lobes, which are again notched. The clusters of flowers are pendulous on long hairy pedicels. The petals are wanting. The calyx is bell-shaped and several times lobed, usually five times. The stamens are variable in number. The ovary is two-lobed and the style deeply forked. The fruit forms two seeds, each with a long wing-like expansion as shown in the figure. The flowers of the maple are polygamo-dicœcious, that, is the male members (stamens) and female members (carpels) may be in the same flower or in different flowers.

Fig. 574.

Seeds and flowers of sugar-maple. At the right is a pistillate flower, in the middle a staminate flower, and at the left the two seeds forming a samara.

SUGGESTIONS FOR STUDY OF THE SUGAR-MAPLE.

1177. The sugar-maple (Acer saccharinum).—(Another species may be studied if desired.)

Leaves.—Determine the form and arrangement of the leaves; sketch a leaf.

Inflorescence.—Describe the character of the inflorescence; sketch a flower cluster.

Flowers.—Select several different flowers, some from different trees, and compare them carefully to see if the members of the flower are the same in all. Sketch several to show the general character.

What parts of the flower are present? Describe the form and character of each set of members, and their relation to each other. Determine the number of members in each set and their relations among themselves. Study several flowers to make this out.

The fruit.—Sketch a fruit. What parts of the flower are united in the fruit?

If there is time, it will be found instructive to compare the flowers of another species of maple, like the red maple, with the sugar-maple. Ex-

amine different flowers from several different trees in order to compare the different sizes of the stamens and pistils in different flowers, and the facts with reference to the presence or absence of any of the members in certain of the flowers. Compare the leaves of the red maple with those of the sugar-maple also.

Material.—Leafy shoots, either fresh or pressed and dried. Flowers; fresh as they appear in the spring; if they cannot be studied immediately, they may be preserved in alcohol or in formalin. They are better fresh.

Fruits, collected when mature preserved dry.

Omit the study of the horse-chestnut unless it is desired to study it instead of the maple, since it belongs to the same order.

1178. The buckeye family (Hippocastanaceæ).—The horse-chestnut (Æsculus hippocastanum) is largely planted in the Northeastern United States as an ornamental tree. It is also self-seeding in waste places. The family is represented in other places by other species, the buckeye, for example, from which the family gets its common name, occurs in Ohio (the Buckeye State).

Suggestions for Study of the Horse-chestnut.

The horse-chestnut (Æsculus hippocastanum).

The leaves.—Note the form and arrangement of the leaves. Sketch a leaf to show its form and the parts. What kind of a leaf is it?

The inflorescence (mixed racemose).—The flowers. What parts of the flower are present? Is the flower complete or incomplete; regular or irregular; perfect or imperfect?

Describe the calyx; the corolla; describe a petal, its form and color. How many petals present?

The stamen.—How many present? Sketch a stamen.

The pistil.—Describe the form of the pistil, its parts; how many carpels are represented in the pistil? What is the character of the surface of the ovary?

The mature fruit.—What is the character of the surface of the mature fruit? Describe the form of the fruit. What parts of the flower are united to form the fruit? What is the difference between the fruit and a seed in the horse-chestnut? Examine the embryo in the seed; note its large cotyledons and the well-developed hypocotyl. Why is the embryo not good for food for man?

Construct the floral diagram of the horse-chestnut flower.

Material.—Sprays of leaves and flowers, collected fresh. Mature fruits.

CHAPTER LXIV.

DICOTYLEDONS CONTINUED.

Topic VIII: Dicotyledons with distinct petals, hypogenous and irregular flowers.

ORDER PARIETALES.

1179. Lesson XVI. The violet family (Violaceæ).—This family is represented by the common blue violet, the yellow violet, the pansies, heartsease, sweet violet, etc.

SUGGESTIONS FOR STUDY OF THE BLUE VIOLET.

The blue violet (Viola cucullata).

The entire plant.—Describe the character and habit of the plant, the short underground stem, the "radicle" leaves, the erect flower-scapes which bear the conspicuous blue flowers, and the short, curved stems beneath the soil or débris which bear the closed inconspicuous flowers. Sketch a leaf, showing the form and venation. What is the form of the leaf and the character of the margin?

The blue flowers.—Sketch a flower. Is the flower regular or irregular; complete or incomplete; perfect or imperfect?

The calyx.—Describe the form of the calyx; how many sepals are indicated?

The corolla.—How many petals are present? Remove them and note carefully the form of each one and the position in the flower. In the "spurred" one look for nectar-glands.

The stamens.—Determine the number of the stamens. Are they united together by their anthers? If so, the stamens are said to be *syngenecious*. Are the stamens of different sizes? Describe the form of the different ones and the relation of certain peculiar ones to the spur of the corolla.

The pistil.—Describe the form of the pistil and the relation of the stamens and pistils.

The closed (cleistogamous) flowers.—These are on shorter, curved, scapes which hold them beneath the soil or débris. Compare them with the blue flowers. What parts of the flower are absent?

The fruit.—Make a cross-section of the fruit and determine how many

Fig. 575.

Viola cucullata; blue flowers above, cleistogamous flowers smaller and curved below. Section of pistil at right.

carpels are represented in the pistil. Note the numerous seeds and their attachment.

Pollination of violets.—If a sweet-violet flower or the flowers of the pansy are convenient, study the stamens and pistil of the open flowers. Remove the corolla, and note the position of the anthers with reference to the pistil. Note the peculiar enlarged stigma with an opening in front,

and the lip below. Move a pencil into a flower, endeavoring to imitate the entrance of an insect, and try to determine how cross-pollination takes place. Compare the blue flowers of the blue violet.

The small closed flowers are called cleistogamous, and they are *self-pollinated*, because being closed, and because of the position of the anthers around the stigma, the pollen from the opening anthers comes directly in contact with the stigma. In the flowers of the pansy cross-pollination often takes place through the agency of insects. While the blue flowers of the blue violet rarely set fruit, nevertheless pollination and fertilization do take place in some of the flowers, though fruit sets more abundantly in the cleistogamous flowers.

Material.—Entire plants with the flowers; collect some early in the season when the blue flowers are abundant, and some later when the small flowers underneath the soil or leaves are formed. Mature fruit is also desirable.

Fig. 576. Section of flower of Œnothera.

Topic IX: Dicotyledons with distinct petals and epigynous flowers.

ORDER MYRTALES.

1180. Lesson XVII. The evening-primrose family (Onagraceæ).—In the evening primrose (œnothera) the flowers are arranged in a loose spike along the end of the stem, each one situated in the axil of a leaf-like bract. The flowers of the family are very characteristic, as shown here. They are sessile in the axil of the bract, and the calyx forms a long tube by the union of the sepals, only the end of the tube being divided into the individual parts, showing four lobes. On the edge of the open end of the calyx-tube are seated the four, somewhat heart-

Fig. 577.

Evening primrose (Œnothera biennis), showing flower-buds, flowers, and seed-pods. (From Kerner and Oliver.)

shaped, yellowish petals, and here are also seated the eight stamens. The four carpels are united into a single pistil within the base of the calyx-tube and united with it, so that the calyx-tube seems to be on the end of the pistil. The flowers soon fade and fall away from the pistil, and this grows into an elongated

Fig. 578.
Wild carrot.

four-angled pod. Since the lower flowers on the stem are the older, we find nearly mature fruit and fresh flowers, with all intermediate grades, on the same plant.

The plants grow by roadsides and in old fields. They are from 10*cm* to a meter or more high (one to five feet). The

leaves are lanceolate or oblong, toothed and repand on the margin. In many of the species of the family the parts of the flower are in fours as in the evening primrose, but in others the number is variable.

ORDER UMBELLALES.

1181. Lesson XVIII. The parsley family (Umbelliferæ). — The wild carrot (Daucus carota) is common in old fields during August and Septem-

Fig. 579.
Single umbel of the wild carrot.

ber. The leaves are deeply divided and the lobes are notched (pinnately decompound). The flowers form *umbels*, since the pedicels are all of

Fig. 580.
Flower of wild carrot

Fig. 581.
Section of flower.

Fig. 582.
Seed of wild carrot.

about the same length, and many of them radiate from the same point. In the carrot, and in most of the parsley family, the umbel is a compound one, as shown in the illustration. The calyx is firmly united with the

walls of the ovary, which is formed of two united carpels. The five white petals as well as the five stamens arise from the margin of the ovary around the two styles. No portion of the calyx is free in the wild carrot, though in some other members of the family there are small calyx teeth. The fruit is bristly and the surface of the umbel becomes concave in age. The floral formula is as follows: Ca_5,Co_5,A_5,G_2.

The cornel or dogwood family and the aralia family both have the flowers in umbels, and are thus related to the parsley family.

CHAPTER LXV.

DICOTYLEDONS CONCLUDED.

Topic X: Dicotyledons with united petals, flower parts in four whorls.

ORDER POLEMONIALES.

1182. Lesson XIX. The mint family (Labiatæ).—The mint family contains a large number of genera and takes its common name from the mints, of which there are several species belonging to the genus Mentha. In the figure of the "dead-nettle" (Lamium amplexicaule), which is also one of the members of this family, we see that the lobes of the irregular corolla are arranged in such a manner as to suggest two lips, an upper and a lower one. From this character of the corolla, which obtains in nearly all the members, the family receives its name of *Labiatæ*. The calyx is five-lobed. The stamens, four in number, arise from the tube of the corolla, and converge in pairs. The ovary is divided into four lobes, and at the maturity of the seed these form four nutlets.

Fig. 583.
Spray of dead-nettle (Lamium amplexicaule), leaves and flowers.

The leaves are rounded, crenate on the margins, the lower ones petioled and heart-shaped, and the upper ones sessile and clasping around the stem beneath the flower clusters. From the clasping character of the upper leaves the plant derives its specific name of *amplexicaule*. The plant occurs in waste places and is rather common.

Fig. 584.
Diagram of Lamium flower.

SUGGESTIONS FOR STUDY OF A LABIATÆ FLOWER.

1183. The catnip (Nepeta cataria).—While the "dead-nettle" is used here to illustrate the mint family, other species may be studied instead. The exercise is written for the catnip (Nepeta cataria), a very common weed occurring from July to September. If fresh material is not at hand when the study is made, dried entire plants, and the flowers, in formalin may be used, unless it is preferred to use fresh material of some other available species. In that case the dead-nettle here illustrated, and the outline, will serve as a guide for the study.

The entire plant.—Note the habit, the character of the branching, the shape of the stem, the character of the surface. Note the form and arrangement of the leaves. Is the plant annual, biennial, or perennial?

The inflorescence.—What is the inflorescence? **The flower**: the parts present; **the calyx**, form and relation of parts; **the corolla**, form, relation of parts, into what two parts is the corolla divided, the name of the two parts, the number of petals in each part, Note the **stamens**, number, size, position in the flower. **The pistil**; sketch a pistil showing the nutlets, the long style.

To study the stamens remove a corolla, split it open down one side and spread it out on a glass slip and mount in water; or pin it to a cork. Examine with a good hand lens, or with the lower power of the microscope.

Construct the floral diagram.

Cross-pollination by insects.—Study the adaptations of the flower for this purpose. The lower lip is the landing place, and the upper lip is the "banner." If there are color markings on any portion of the flower which serve to guide the insect in entering the flower, describe them and note the location. With a needle imitate the entrance of an insect into the flower and determine the way in which cross-pollination takes place.

Compare if possible other members of the mint family in the study of cross-pollination.

Material.—Entire plant with flowers and ripe fruit. If fresh plants are

not at hand, those that have been pressed and dried may be used for the study of the entire plant and of the leaves. The flowers may be preserved in formalin.

1184. Lesson XX. The figwort family (Scrophulariaceæ).—The mullein (Verbascum), toad-flax (Linaria), turtle-head (Chelone), etc., are members of the figwort family. The plants are mostly herbs. The stamens are usually didynamous (four in two pairs, one pair shorter than the other) or diandrous (two stamens). The stamens are inserted on the two-lipped corolla-tube, which is more or less irregular. In some genera there are five stamens, as in Verbascum.

Suggestions for Study of a Figwort.

The Toad-flax (Linaria vulgaris).—The toad-flax is widely distributed, growing in waste places as a weed from June to October.

The entire plant.—Note the short, pale green perennial rootstock; the longer erect annual stem; is it simple or branched? Leaves, form, and arrangement.

The inflorescence.—The kind of inflorescence. **The flower.**—What parts of the flower are present? Describe the different parts. **The calyx.**—How many sepals indicated? What is the form of the calyx? **The corolla.**—Form. How many petals indicated? Describe the form of the corolla and its parts. **The stamens.**—How many, their position, size? What is the significance of the difference in the size of the stamens? **The pistil.**—Form, parts; form of the ovary; how many carpels present in the pistil?

Study the adaptation of the flower for cross-pollination by the aid of insects; the lower lip of the corolla as a landing place; since insects are supposed to be attracted by bright colors, what portion of the flower serves thus to direct the insect?

Note the spur on the corolla, and the nectary inside; what kinds of insects visit this flower? Imitate with the end of a pencil the entrance of an insect in a flower and endeavor to make out how cross-pollination takes place.

Seed distribution.—Examine ripe seed-pods, dry some of them, and then take some of the dry ones and place in water. Describe the action of the pod in scattering the seeds, and the causes.

Other members of the family are interesting to compare with the toad-flax, as the beard-tongue (Penstemon pubescens), turtle-head (Chelone glabra), monkey-flower (Mimulus ringens), etc.

Material.—Entire plants with the underground stems. Flowers and fruit. If fresh material cannot be had at the time of the study, dried plants (pressed) will answer for the study of the entire plant. Flowers may be preserved in formalin; fruits dry.

ORDER CAMPANULALES.

1185. Lesson XXI. The thistle family (Compositæ).—In all the composites, the flowers are grouped (aggregated) into "heads," as in the sunflower, where each head is made up of a great many flowers crowded closely together on a widened receptacle. The family is a large one, and is divided into several sections according to the kinds of flowers and the different ways in which they are combined in the head. In the asters there is one common type illustrated in fig. 585 by the *Aster novæ-angliæ*. In the aster, as is well shown in the figures, the head is composed of two kinds of flowers, the tubular flowers and the ray

Fig. 585.
Aster novæ-angliæ.

Fig. 586.
Head of flowers of Aster novæ-angliæ.

flowers. In the tubular flowers the corolla is united to form a slender tube, which is five-notched at the end, representing the five petals. In the ray flowers the corolla

is extended on one side into a strap-shaped expansion. Together these strap-shaped corollas form the "rays" of the head. The corolla is split down on one side, which permits the

Fig. 587. Ray flower of Aster novæangliæ.

Fig. 588. Tubular flower of aster.

Fig. 589. Tubular flower opened to show syngenecious stamens.

Fig. 590. Syngenecious stamens opened to show style and two stigmas.

end then to expand and form the "strap." This is a *ligula*, or more correctly speaking a *false ligula*. In fact the ray flower is *bilabiate*. By counting the "teeth" of the false ligula there are found only three, which indicates that the strap here is made up of only three parts of the 5-merous corolla. The two other limbs of the corolla are rudimentary, or suppressed, on the opposite side of the tube. True ligulate flowers are found in the chicory, dandelion, or in the hieracium, where the five points are present on the end of the ligula.

The calyx tube in the aster, as in all of the composites, is united with the ovary, while the limb is free. In the aster, as in many others, the limb is divided into slender bristles, the *pappus*. (In some of the composites the pappus is in the form of scales.) The stamens are united by their anthers into a tube (syngenecious) which closely surrounds the style. (In Ambrosia the anthers are sometimes distinct.) The style in pushing

through brushes out some of the pollen from the anthers and bears it aloft as in the bell-flower, but the stigmatic surface is not yet mature and expanded, so that close pollination cannot take place. There are usually no stamens in the ray flowers. The ovary is composed of two carpels, as is shown by the two styles, but there is only one locule, containing an erect, anatropous, ovule.

Fig. 591.
Diagram of composite flower. (Vines.)

The floral formula for the composite family then is as follows: Ca_5,Co_5,A_5,G_2. A number of the composites have only tubular flowers, as in the thoroughwort (Eupatorium) and everlasting (Antennaria).

Suggestions for Study of an Aster.

1186. The aster (Aster novæ-angliæ).—(Some other species may be selected if it is more convenient.)

The entire plant.—Describe the entire plant; the character of the stem; the position of the leaves; their form on different portions of the stem; their attachment to the stem. Compare the "radicle" leaves with the stem leaves.

The inflorescence.—Describe the inflorescence, and the position of the flower heads.

A single head of flowers.—Describe the involucre. What different kinds of flowers are present? What is the position of each kind in the head? Determine the approximate number of each kind of flowers in a head.

The ligulate flowers.—Remove one from the head and sketch it, showing the different parts. How many petals are indicated in the strap? How many petals are in the tubular portion of the ligulate flower? Is this a t.ue ligula? Why? Is the calyx present, and what represents it? Split open the corolla-tube, and determine whether or not the stamens are present. Is the pistil present in the ligulate flower?

The tubular flowers.—Describe the corolla. How many petals are indicated in the corolla-tube? What is such a corolla called?

The stamens.—Split open the corolla-tube down one side, and sketch to show the position of the stamens, and their relation to each other. Split open the anther column, spread it out, and sketch to show the relation of the stamens to each other, and the pistil within.

Material.—Entire plants in flower; also some of the mature fruit heads.

The goldenrod (Solidago).—(As an alternate, if desired, for the aster.)

If it is desired to study the goldenrod instead of the aster, it will be well to make a comparison with the aster, and the account of the aster here given will serve as a guide for the study of the goldenrod. The daisy is also a good one to compare with the aster, and the outline for the study of the aster here given will answer for the basis of such a study.

Fig. 502.
Rattlesnake-weed (Hieracium venosum).

1187. Lesson XXII. The chickory family (Cichoriaceæ). — The rattlesnake-weed (Hieracium venosum) is an example of another type, with only one kind of flower in the head, the true ligulate flower. The hawkweed, or devil's paint-brush (H. aurantiacum), is a related species, which is a troublesome weed. The dandelion and prickly lettuce are also members of the ligulate-flowered composites.

These ligulate-flowered composites are now usually separated from the other composites as a distinct family (the chicory family) Cichoriaceæ, which stands just before the Compositæ.

Suggestions for Study of the Dandelion.

1188. The dandelion (Taraxacum dens leonis).

The entire plant.—Note the very short stem (the plant is sometimes said to be acaulescent, but it has a short stem). Note the thick root; the position of the leaves (often called radicle leaves because of their position on the short stem so near the roots). Sketch a leaf to show its form.

The inflorescence.—What is the kind of inflorescence? Note the leafless stem (flowering scape) which bears the head of flowers. Cut across the stem and split it, and then describe its character.

The involucre.—How many whorls of bracts are there in the involucre? Comparing plants in flower and at different stages of maturity, describe the different positions of the involucre.

The flowers.—Are all the flowers strap-shaped? Note the ligula. Why is it a true ligula? Describe and sketch a single flower.

The calyx.—What represents the calyx? Describe the free portion, or limb. What is the insertion of the calyx?

The corolla.—What represents the corolla, and how many petals are indicated?

The stamens.—What is the relation of the stamens to each other? What is the name applied to such stamens? Sketch a few of the stamens to show their relation to each other.

The pistil.—How many carpels are represented in the pistil? What is the indication of this? What is the relation of the different sets of the flower to each other, and what is their insertion? Give the names applied to these different relations.

The fruit.—Comparing the different stages of the ripening seed, describe the changes which take place in the different parts of the flower and head. What parts of the flower are united in the fruit? What is such a fruit called? How many seeds in the fruit?

Seed distribution.—How are seeds of the dandelion adapted for seed distribution? Take a head of ripe seeds, and blow upon it. Note how the seeds float; observe which end falls first upon the ground (see Chapter XLV, Seed Dispersal).

Cross-pollination.—In some of the composites, as in the daisy or in the sunflower, determine what provision is present for cross-pollination. Do all the flowers "blossom" at the same time in a single head? Which ones blossom first? Do the stamens ripen and emerge from the throat of the corolla at the same time as the stigma in the same flower? Why? Compare the dandelion in these respects.

Material.—Entire plants, with flowers (they can be obtained all through the spring); heads of fruit in different stages of maturity.

1189. The extent to which the union of the parts of the flower has been carried in the composites, and the close aggregation of the flowers in a head, represent the highest stage of evolution reached by the flowers of the angiosperms. The composites stand just above the bell-flowers and lobelias, at the termination of a series (see paragraphs 1221, 1222). The teasels show a relationship to the composites in the aggergation of the flowers in a head. But the consolidation of the parts of the flower has not been carried so far, and the flowers are each separated by an "epicalyx" in the form of a minute cup-shaped involucre. The teasels stand at the termination of another series in which are the lonicera and valerian families. The gynœcium of the composites presents a highly specialized structure. The ovary is plainly made up of two carpels, as shown by the two styles and the internal structure, but it becomes reduced to a one-seeded achene. From the five carpels in the pyrolas to the composites there is a gradual tendency toward reduction in number of the carpels to two, and in the composites the highest specialization is reached in the consolidation of these into one achene in fruit.

CHAPTER LXVI.

CLASSIFICATION OF THE ANGIOSPERMS.

Group Anglospermæ.

I. CLASS MONOCOTYLEDONES.

1190. Order Pandanales.—Aquatic or marsh plants. The cattail flags (Typha) and the bur-reeds (Sparganium), each representing a family. The name of the order is taken from the tropical genus Pandanus (the screw-pine often grown in green-houses).

1191. Order Naiadales.—Aquatic or marsh herbs. Three families are mentioned here.

The pondweed family (Naiadaceæ), named after one genus, Naias. The largest genus is Potamogeton, the species of which are known as pondweeds. Ruppia occidentalis occurs in saline ponds in Nebraska, and R. maritima along the seacoast and in saline districts in the interior.

The water-plantain family (Alismaceæ) includes the water-plantain (Alisma) and the arrow-leaves (Sagittaria).

The tape-grass family (Vallisneriaceæ) includes the tape-grass, or eel-grass (the curious Vallisneria spiralis).

1192. Order Graminales.—Two families.

The grass family (Gramineæ), the grasses and grains.

The sedge family (Cyperaceæ), the sedges.

1193. Order Palmales, with one family, Palmaceæ, includes the palms, abundant in the tropics and extending into Florida. Cultivated in greenhouses.

1194. Order Arales. (See Chapter LX.)

The arum family (Araceæ). Flowers in a fleshy spadix. Examples: Indian turnip (Arisæma), sweet-flag (Acorus), skunk-cabbage (Spathyema).

The duckweed family (Lemnaceæ). (Examples: Lemna, Spirodela, Wolffia. See paragraphs 51–53.)

1195. Order Xyridales, from the genus Xyris, the yellow-eyed grass family (Xyridaceæ). Species mostly tropical, but a few in North America. Other examples are the pipewort family (Eriocaulaceæ, example, Eriocaulon septangulare), the pineapple family (Bromeliaceæ, example, the pineapple cultivated in Florida); the Florida moss or hanging moss (Tillandsia usneoides); the spiderwort family (Commelinaceæ), including the spiderwort (Tradescantia, several species in North America); the pickerel-weed family (Pontederiaceæ), including the genus Pontederia in borders of ponds and streams.

1196. Order Liliales.—(See Chapter LIX). Some of the families are as follows:

The rush family (Juncaceæ, example, Juncus), with many species, plants of usually swamp habit.

The lily family (Liliaceæ, examples: Lilium, Allium = Onion, Erythronium, Yucca).

The iris family (Iridaceæ, examples: Iris, the blue-flag, fleur-de-lis, etc.).

The lily-of-the-valley family (Convallariaceæ, examples: lily-of-the-valley, Trillium, etc.)

The amaryllis family (Amaryllidaceæ, examples: Narcissus, the daffodil; Cooperia, in southwestern United States).

1197. Order Scitaminales.—This order includes the large showy cultivated Canna of the canna family.

1198. Order Orchidales. Example, the orchid family (Orchidaceæ, see Chapter LIX) with Cypripedium, Orchis, etc.

II. CLASS DICOTYLEDONES.

SERIES 1. CHORIPETALÆ. Petals wanting (Apetalæ, or Archichlamydæ of some authors), or present and distinct from one another (Polypetalæ, or Metachlamydæ).

1199. Order Casuarinales, confined to tropical seacoasts (example, Casuarina).

1200. Order Piperales includes the lizard's-tail family (Saururaceæ), Saururus cernuus, lizard's-tail, in the eastern United States.

1201. Order Salicales.—Shrubs or trees, flowers in aments. Includes the willows and poplars (Salix and Populus of the willow family, Salicaceæ. See Chapter LXI.)

1202. Order Myricales.—Shrubs or small trees. Includes the sweet-gale (Myrica gale) in wet places in northern United States and British North America, Myrica cerifera forming thickets on sand-dunes along the Atlantic coast, and the sweet-fern (Comptonia peregrina=C. asplenifolia) in the eastern United States in dry soil of hillsides.

1203. Order Leitneriales.—Shrubs or trees. Includes the cork-wood, Leitneria floridana (Leitneriaceæ).

1204. Order Juglandales.—Trees, staminate flowers in aments. The walnut family (Juglandaceæ, examples: walnut, butternut, etc. Juglans; hickory, Hicoria=Carya.

1205. Order Fagales.—Trees and shrubs. Flowers in aments, or the pistillate ones with an involucre which forms a cup in fruit, as in the acorn of the oak.

The birch family (Betulaceæ, examples: Betula, birch; Corylus, hazelnut; Alnus, alder, etc.).

The beech family (Fagaceæ=Cupuliferæ, examples: Fagus, beech; Castanea, chestnut; Quercus, oak. See Chapter LXI).

1206. Order Urticales.—Trees, shrubs, or herbs. Examples: the elm family (Ulmaceæ. See Chapter LXII), the mulberry family (Moraceæ), and the nettle family (Urticaceæ).

1207. Order Santalales, herbs or shrubs, mostly parasitic.

The mistletoe family (Loranthaceæ), with the American mistletoe (Phoradendron flavescens), parasitic on deciduous trees in the South Atlantic, Central, and Gulf States (N. J. to Ind. Ter.).

The sandalwood family (Santalaceæ, example, the bastard toad-flax, Comandra umbellata), widely distributed in North America.

1208. Order Aristolochiales.—Herbs or vines with heart-shaped or kidney-shaped leaves. The birthwort family (Aristolochiaceæ, example, Aristolochia serpentaria, the Virginia snake-root, eastern United States; wild ginger, or heart-leaf, Asarum canadense, eastern North America.)

1209. Order Polygonales.—Examples: the buckwheat family (Polygonaceæ), including buckwheat (Fagopyrum), and numerous species of Polygonum, known as smartweed, water-pepper, tear-thumb, bindweed, knotweed, prince's-feather, etc.

1210. Order Chenopodiales.—Herbs. There are several families; one of the largest is the goosefoot family (Chenopodiaceæ). The genus Chenopodium includes many species, known as goosefoot, lamb's-quarters, etc. Here belong also the Russian thistle (Salsola tragus) and the saltwort (S. kali). The former is sometimes a troublesome weed in the central and western United States, naturalized from Europe. The latter occurs along the Atlantic coast on seabeaches. Atriplex occurs in salty or alkaline soil, also the glasswort (Salicornia herbacea), the bugseed (Corispermum). The pokeweed family (Phytolaccaceæ), the Amaranth family (Amaranthaceæ), the purslane family (Portulacaceæ, including the purslane or "pursley," Portulaca oleracea, and the spring-beauty, Claytonia virginica), and the pink family (Caryophyllaceæ), belong here.

1211. Order Ranales.—Herbs, shrubs, or trees. Examples are:

The water-lily family (Nymphæaceæ), with the yellow water-lily (Nymphæa advena = Nuphar advena) and the white water-lily (Castalia odorata = Nymphæa odorata).

The magnolia family (Magnoliaceæ), including the mag-

nolias (Magnolia) and the tulip-tree (Liriodendron). The crowfoot family (Ranunculaceæ), with the buttercups, hepatica, clematis, etc. (See Chapter LXII).

1212. Order Papaverales.—Mostly herbs. Examples are:

The poppy family (Papaveraceæ), including the opium or garden poppy (Papaver somniferum), the blood-root (Sanguinaria canadensis), the Dutchman's-breeches (Bicuculla cucullaria = Dicentra cucullaria), squirrel's-corn (Bicuculla canadensis = D. canadensis).

The mustard family (Cruciferæ), including the toothwort (Dentaria), shepherd's-purse (Bursa bursa-pastoris = Capsella bursa-pastoris, see Chapter LXII), the cabbage, turnip, etc.

1213. Order Sarraceniales.—Insectivorous plants.

The pitcher-plant family (Sarraceniaceæ). Examples: Sarracenia purpurea, the pitcher-plant, in peat-bogs, northern and eastern North America.

The sundew family (Droseraceæ). Examples: Drosera rotundifolia, and other sundews.

1214. Order Rosales.—Herbs, shrubs or trees. Seventeen families are given in the eastern United States. Examples:

The riverweed family (Podostemaceæ), containing the riverweed (Podostemon).

The saxifrage family (Saxifragaceæ), containing a number of species. Example, Saxifraga virginiensis.

The gooseberry family (Grossulariaceæ), including the wild and the cultivated gooseberry.

The witch-hazel family (Hamamelidaceæ), including the witch-hazel (Hamamelis), in eastern North America, and the sweet-gum (Liquidambar styraciflua).

The plane-tree family (Platanaceæ), with the plane-tree, or buttonwood (Platanus occidentalis), eastern North America. (Other species occur in western United States.)

The rose family (Rosaceæ), including roses, spiræas, raspberries, strawberries, the shrubby cinquefoil (Dasiphora fruticosa), etc.

The apple family (Pomaceæ), including the apple, mountain-

ash, pear, June-berry (or shadbush, also service-berry), the hawthorns (Cratægus, see Chapter LXIII).

The plum family (Drupaceæ), including the cherries, plums, peaches, etc.

The pea family (Papilionaceæ), including the pea, bean, clover, vetch, lupine, etc., a very large family.

1215. Order Geraniales.—Herbs, shrubs, or trees. Nine families in the eastern United States. Examples:

The geranium family (Geraniaceæ), with the cranesbill (Geranium maculatum) and others.

The wood-sorrel family (Oxalidaceæ), with the wood-sorrel (Oxalis acetosella) and others.

The flax family (Linaceæ). Example, flax (Linum vulgaris).

The spurge family (Euphorbiaceæ). Plants with a milky juice, and curious, degenerate flowers. Examples: the castor-oil plant (Ricinus), the spurges (many species of Euphorbia).

1216. Order Sapindales.—Mostly trees or shrubs. Twelve families in the eastern United States. Examples:

The sumac family (Anacardiaceæ), containing the sumacs in the genus Rhus. (Examples: the poison-ivy (R. radicans), a climbing vine, in thickets and along fences, in eastern United States. Sometimes trained over porches. The poison-oak (R. toxicodendron), a low shrub. Poison-sumac or poison-alder (R. vernix=R. venenata), sometimes called "thunderwood," or dogwood, is a large shrub or small tree, very poisonous. The smoke-tree (Cotinus cotinoides) belongs to the same family, and is often planted as an ornamental tree. The maple family (Aceraceæ), including the maples (Acer, see Chapter LXIII).

The buckeye family (Hippocastanaceæ), including the horse-chestnut (Æsculus hippocastanum), much planted as a shade tree along streets. Also there are several species of buckeye in the same genus.

The jewelweed family (Balsaminaceæ), including the touch-me-not (Impatiens biflora and aurea) in moist places. The garden balsam (Imp. balsamea) also belongs here.

1217. Order Rhamnales.—Shrubs, vines, or small trees. There are two families, the buckthorn (Rhamnaceæ), the grape family (Vitaceæ), including the grapes (Vitis), the American ivy (Parthenocissus quinquefolia=Ampelopsis quinquefolia), in woods and thickets, eastern North America, and much planted as a trailer over porches. The Japanese ivy (P. tricuspidata=A. veitchii) used as a trailer on the sides of buildings belongs here.

1218. Order Malvales.—Herbs, shrubs, or trees.

The linden family (Tiliaceæ). Example, the basswood or American linden (Tilia americana.)

The mallow family (Malvaceæ), including the hollyhock, the mallows, rose of Sharon (Hibiscus), etc.

1219. Order Parietales, with seven families in the eastern United States. The St.-John's-wort (Hypericum) and the violets each represent a family. The violets (Violaceæ) are well-known flowers.

1220. Order Opuntiales.—These include the cacti (Cactaceæ), chiefly growing in the dry or desert regions of America.

1221. Order Thymeleales, with two families and few species.

1222. Order Myrtales.—Land, marsh, or aquatic plants. The most conspicuous are in the evening primrose family (Onagraceæ), including the fireweeds, or willow herbs (Epilobium), and the evening primrose (Onagra biennis=Œnothera biennis).

1223. Order Umbellales.—Herbs, shrubs, or trees, flowers in umbels.

The ginseng family (Araliaceæ). This includes the spikenards and sarsaparillas in the genus Aralia, and the ginseng (or "sang"), Panax quinquefolium.

The carrot family (Umbelliferæ). This family includes the wild carrot (Daucus carota), the poison-hemlock (Cicuta), the cultivated carrot and parsnip, and a large number of other genera and species.

The dogwood family (Cornaceæ). The flowering dogwood

(Cornus florida), abundant in eastern North America, is an example.

SERIES 2 GAMOPETALÆ (=Sympetalæ or Metachlamydæ). Petals partly or wholly united, rarely separate or wanting.

1224. Order Ericales.—There are six families in eastern United States. Examples:

The wintergreen family (Pyrolaceæ), including the shin-leaf (Pyrola elliptica).

The Indian-pipe family (Monotropaceæ), with the Indian-pipe (Monotropa uniflora) and other humus saprophytes. (See paragraphs 182–191.)

The heath family (Ericaceæ). Examples: Labrador tea (Ledum), in bogs and swamps in northern North America. The azaleas, with several species widely distributed, are beautiful flowering shrubs, and many varieties are cultivated. The rhododendrons are larger with larger flower-clusters, also beautiful flowering shrubs. R. maximum in the Alleghany Mountains and vicinity, from Nova Scotia to Ohio and Georgia. R. catawbiense, usually at somewhat higher elevations, Virginia to Georgia. The mountain laurel (Kalmia latifolia) and other species rival the rhododendrons and azaleas in beauty. The trailing arbutus (Epigæa repens) in sandy or rocky woods is a well-known small trailing shrub in eastern North America. The sourwood (Oxydendrum arboreum) is a tree with white racemes of flowers in August, and scarlet leaves in autumn. The spring or creeping wintergreen (Gaultheria procumbens) is a small shrub with aromatic leaves, and bright red spicy berries.

The huckleberry family (Vaccinaceæ) includes the huckleberries (example, Gaylussacia resinosa, the black or high-bush huckleberry, eastern United States), the mountain cranberry (Vitis-Idæa vitisidæa=Vaccinium vitisidæa) in the northern hemisphere; the bilberries and blueberries (of genus Vaccinium); the cranberries (examples: the large American cranberry, Oxycoccus macrocarpus and the European cranberry, Oxycoccus oxycoccus, in cold bogs of northern North America, the latter also in Europe and Asia).

1225. Order Primulales.—Two families here. The primrose family (Primulaceæ) contains the loosestrifes (Steironema), starflower (Trientalis), etc.

1226. Order Ebenales.—Of the four families, the ebony family (Ebenaceæ) contains the well-known persimmon (Diospyros virginiana) and the storax family (Styracaceæ) with the silverbell, or snowdrop tree (Mohrodendron carolinum).

1227. Order Gentianales.—Herbs, shrubs, vines, or trees. Six families in the United States.

The olive family (Oleaceæ) includes the common lilac (Syringa), the ash trees (Fraxinus), the privet (Ligustrum).

The gentian family (Gentianaceæ) among other genera includes the gentians (Gentiana).

The milkweed family (Asclepiadaceæ) contains plants mostly with a milky juice. Asclepias with many species is one of the most prominent genera.

1228 Order Polemoniales.—Mostly herbs, rarely shrubs and trees. Fifteen families in the eastern United States.

The morning-glory family (Convolvulaceæ) includes the bindweeds (Convolvulus), the morning-glory (Ipomæa), etc.

The dodder family (Cuscutaceæ) includes the dodders, or "love-vines." There are nearly thirty species in the United States. The stems are slender and twine around other plants upon which they are parasitic (see paragraph 179).

The phlox family (Polemoniaceæ). The most prominent genus is Phlox. Over forty species occur in North America.

The borage family (Boraginaceæ) includes the heliotrope (Heliotropium), the hound's-tongue (Cynoglossum), the forget-me-not (Myosotis), and others.

The vervain family (verbenaceæ) contains the verbenas.

The mint family (Labiatæ) contains the mints (Mentha), skullcap (Scutellaria), dead-nettles (Lamium).

The potato family (Solanaceæ) includes the ground-cherry (Physalis), the nightshades (Solanum), the tomato (Lycopersicon), tobacco (Nicotiana).

The figwort family (Scrophulariaceæ) includes the common

mullein (Verbascum), the monkey-flower (Mimulus), the toad-flax (Linaria), turtle's-head (Chelone), and many other genera and species.

The bladderwort family (Lentibulariaceæ) includes the curious bog or aquatic plants with finely dissected leaves, and with bladders in which insects are caught (Utricularia).

The trumpet-creeper family (Bignoniaceæ) includes the trumpet-creeper (Bignonia), the catalpa tree, and others.

1229. Order Plantaginales with one family (Plantaginaceæ) includes the plantains (Plantago).

1230. Order Rubiales with three families is represented by

The madder family (Rubiaceæ) with the bluets (Houstonia), the button-bush (Cephalanthus), the partridge-berry (Mitchella), the bedstraws (Galium), etc.

The honeysuckle family (Caprifoliaceæ) with the elder (Sambucus), the arrowwoods and cranberry trees (Viburnum), the honeysuckles (Lonicera), etc.

1231. Order Valerianales with two families includes

The teasel family (Dipsacaceæ). Example, Fuller's teasel (Dipsacus).

1232. Order Campanulales with five families, the corolla usually gamopetalous.

The gourd family (Cucurbitaceæ) includes the pumpkin, squash, melon, and a few feral species. Example, the star-cucumber (Sicyos angulatus), in moist places in eastern and middle United States.

The bell-flower family (Campanulaceæ) includes the harebells or bell-flowers (Campanula), the lobelias (example, Lobelia cardinalis, the cardinal-flower), etc.

The chicory family (Cichoriaceæ) includes the chicory or succory (Cichorium intybus, known also as blue-sailors), the oyster-plant or salsify (Tragopogon porrifolius), the dandelion (Taraxacum taraxacum=T. densleonis), the lettuce (Lactuca), the hawkweed (Hieraceum) (see paragraph 1177), and others.

The ragweed family (Ambrosiaceæ) includes the ragweeds (Ambrosia), the cockle-bur (Xanthium), and others.

The thistle family (Compositæ) includes the thistle (Carduus), asters (Aster), goldenrods (Solidago), sunflowers (Helianthus), eupatoriums or joepye-weeds, thoroughworts (Eupatorium), cone-flowers or black-eyed Susans (Rudbeckia), tickseed (Coreopsis), bur-marigold or beggar-ticks or devil's-bootjack (Bidens), chrysanthemums, etc.

Absorption by aquatic plants through roots (see paragraph 952).—Aquatic plants which are rooted to the soil in a number of cases have been found to have root hairs. Experiment has demonstrated in these cases that mineral foods are largely taken from the soil and not from the surrounding water. Examples of such plants are Vallisneria spiralis, Ranunculus aquatilis, Elodea canadensis, Potamogeton perfoliatus. The latter made 480 per cent better growth when rooted in soil than when rooted in sand. Such plants, therefore, taking their mineral food from the soil, when they decay increase the amount of food for the plankton or floating plants, or those merely anchored but without well-developed roots or root hairs. See Pond, Raymond H., Biological relation of aquatic plants to the substratum, U. S. Fish Commission Report for 1903, pp. 483–526, 1905. Also, How rooting aquatic plants influence the nutrition of the food fishes of our Great Lakes, Pop. Sci. Month., pp. 251, 254, 5 figures in text, March 1906.

To prepare Fehling's solution.—Make up two stock solutions as follows:

A	Copper sulphate	34.639 grams.
	Distilled water	500 cc.
B	Sodium hydroxide (caustic soda sticks)	50 grams.
	Rochelle salts	173 grams.
	Distilled water	500 cc.

When ready to use, prepare Fehling's solution by mixing equal volumes of A and B. If the Fehling's solution is old, or has sediment, bring it to boil for a minute or two and filter.

Another formula for the stock solutions is as follows:

1	Copper sulphate	9 grams.
	Distilled water	250 cc.
2	Potassium hydroxide (caustic potash sticks)	30 grams.
	Distilled water	250 cc.
3	Rochelle salts	43 grams.
	Distilled water	250 cc.

When ready to use, make Fehling's solution by taking equal volumes of each 1, 2 and 3, and to the mixture add an equal volume of distilled water. If old or there is a precipitate, boil and filter.

APPENDIX.

COLLECTION AND PRESERVATION OF MATERIAL.

Spirogyra may be collected in pools where the water is present for a large part of the year, or on the margins of large bodies of water. To keep fresh, a small quantity should be placed in a large open vessel with water in a cool place fairly well lighted. In such places it may be kept several months in good condition.

Mucor may be obtained by placing old bread, etc., or horse dung, in a moist covered vessel. In the course of a week there should be an abundance of the mycelium and gonidia. From this material cultures may be made, if desired, in nutrient gelatin or nutrient agar.

Saprolegnia, or water mould, can be used for a study of protoplasm. Collect several dead house flies from window sills of neglected rooms. Immerse them in alcohol, then rinse in water to remove the alcohol. Then throw them in vessels of water containing freshly collected algæ from several different places. In the course of a week there should be a tuft of whitish threads of the water mould surrounding the fly.

Nitella is obtained in rather deep pools or ponds, or in slow-running water, at a depth of one to three feet usually.

Stamen hairs of tradescantia can usually be obtained in greenhouses from flower buds just ready to open or just after opening.

Œdogonium is often found in floating mats in ponds, or on the margins of slow-running streams, or of lakes. Frequently it is attached to other aquatic plants. Fruiting plants can be

detected by certain of the cells being rounded and broader than others, and some of them at least usually containing the spores, a single spore nearly or quite filling the large cell, or oogonium. When it cannot be studied fresh it may be preserved in 2% formalin or in 70% alcohol, first placing it successively in 25% and 50% alcohol for a few hours.

Some species of vaucheria occur in places frequented by œdogonium or spirogyra, while others occur in running water, or still others on damp ground. Frequently fine specimens of vaucheria in fruit may be found during the winter growing on the soil of pots in greenhouses. The jack-in-the-pulpit, also known as Indian turnip, growing in damp ground I have found when potted and grown in the conservatory yields an abundance of the vaucheria, probably the spores of the alga having been transferred with the soil on the plants. When material cannot be obtained fresh for study, it may be preserved in advance in formalin or alcohol as described for œdogonium.

Coleochæte scutata is not so common as the œdogonium, spirogyra, or vaucheria. But it may be sometimes found with the small circular green disks adhering to rushes, grasses, or other aquatic plants in large ponds or on the margins of lakes. When found it is well to make permanent mounts of material killed in formalin, either in glycerine or glycerine jelly.

Wheat rust.—The cluster-cup stage may be collected in May or June on the leaves of the barberry. Some of the affected leaves may be dried between drying-papers. Other specimens should be preserved in 2% formalin or in 70% alcohol. If the cluster cup cannot be found on the barberry, other species may be preserved for study.

The uredospore and teleutospore stages can usually be found abundantly on wheat and oats, especially on late-sown oats which ripen in autumn. The affected leaves and stems may be preserved dry.

The powdery mildews are common during summer and autumn on a variety of leaves of shrubs, herbs, and trees. They can be recognized by the mildewed spots, or by the numerous

minute black specks on the surface of the leaf. The leaves should be preserved dry after drying under pressure.

Liverworts.

Marchantia.—The green thallus (gametophyte) of marchantia may be found at almost any season of the year along shady banks washed by streams, or on the wet low shaded soil. Plants with the cups of gemmæ are found throughout a large part of the year. They are sometimes found in greenhouses, especially where peat soil from marshy places is used in potting. In May and June male and female plants bear the gametophores and sexual organs. These can be preserved in 2½% formalin or in 70% alcohol. If one wishes to preserve the material chiefly for the antheridia and archegonia a small part of the thallus may be preserved with the gametophores, or the gametophores alone.

In July the sporogonia mature. When these have pushed out between the curtains underneath the ribs of the gametophore, they can be preserved for future study by placing a portion of the thallus bearing the gametophore in a tall vial with 2% formalin. Plants with the sporogonia mature, but not yet pushed from between the curtains on the under side, can be collected in a tin box which contains damp paper to keep the plants moist. Here the sporogonia will emerge, and by examining them day by day, when some of the sporogonia have emerged, these plants can be quickly transferred to the vials of formalin before the sporogonia have opened and lost their spores. In this condition the plant can be preserved for several years for study of the gross character of the sporogonia and the attachment to the gametophyte. From some of the other plants permanent mounts in glycerine jelly may be made of the spores and elaters.

Riccia.—Riccia occurs on muddy, usually shaded ground. Some species float on the surface of the water. It may be preserved in 2% formalin or 70% alcohol.

Cephalozia, ptilidium, bazzania, jungermannia, frullania, and other foliose liverworts may be found on decaying logs, on the

trunks of trees, in damp situations. They may be preserved in formalin or alcohol. Some of the material may also be dried under pressure.

Mosses are easily found and preserved. Male and female plants for the study of the sexual organs should be preserved in formalin or alcohol. In all these studies whenever possible living material freshly collected should be used.

Ferns.

For the study of the general aspect of the fern plant, polypodium, aspidium, onoclea, or other ferns may be preserved dry after pressure in drying sheets. A portion of the stem with the leaves attached should be collected. These may be mounted on stiff cardboard for use. The sporangia and spores can also be studied from dried material, but for this purpose the ferns should be collected before the spores have been scattered, but soon after the sporangia are mature. But when greenhouses are near it is usually easy to obtain a few leaves of some fern when the sporangia are just mature but not yet open. To prevent them from opening and scattering the spores in the room before the class is ready to use them, immerse the leaves in water until ready to make the mounts; or preserve them in a damp chamber where the air is saturated with moisture.

For study of the prothallia of ferns, spores should be caught in paper bags by placing therein portions of leaves bearing mature sporangia which have not yet opened. They should be kept in a rather dry but cool place for one or two months. Then the spores may be sown on well-drained peat soil in pots, and on bits of crockery strewn over the surface. Keep the pots in a glass-covered case where the air is moist and the light is not strong. If possible a gardener in a conservatory should be consulted, and usually they are very obliging in giving suggestions or even aid in growing the prothallia.

Lycopodium, equisetum, selaginella, isoetes, and other pteridophytes desired may be preserved dry and in 70% alcohol.

Pines.—The ripe cones should be collected before the seeds

scatter, and be preserved dry. Other stages of the development of the female cones should be preserved either in 70% alcohol or in 2½% formalin. The male cones should be collected a short time before the scattering of the pollen, and be preserved either in alcohol or formalin.

Angiosperms.—In the study of the angiosperms, if it is desired to use trillium in the living state for the morphology of the flower before the usual time for the appearance of the flower in the spring, the root-stocks may be collected in the autumn, and be kept bedded in soil in a box where the plants will be subjected to conditions of cold, etc., similar to those under which the plants exist. The box can then be brought into a warm room during February or March, a few weeks before the plants are wanted, when they will appear and blossom. If this is not possible, the entire plant may be pressed and dried for the study of the general appearance and for the leaves, while the flower may be preserved in 2½% formalin, of course preserving a considerable quantity. Other material for the study of the plant families of angiosperms may be preserved dry, and the flowers in formalin, if they cannot be collected during the season while the study is going on.

Demonstrations.—Upon some of the more difficult subjects in any part of the course, especially those requiring sections of the material, demonstrations may be made by the teacher. The extent to which this must be carried will depend on the student's ability to make free-hand sections of the simpler subjects, upon the time which the student has in which to prepare the material for study, and the desirability in each case of giving demostrations on the minuter anatomy, the structure of the sexual organs and other parts, in groups where the material should be killed and prepared according to some methods of precision, now used in modern botanical laboratories. The more difficult demonstrations of this kind should be made by the instructor, and such preparations once made properly can be preserved for future demonstrations. Some of them may be obtained from persons who prepare good slides, but in such cases fancy preparations of

curious structures should not be used, but slides illustrating the essential morphological and developmental features. Directions for the preparation of material in this way cannot be given, in this elementary book, for want of space.

Method of taking notes, etc.—In connection with the practical work the pupil should make careful drawings from the specimens; in most cases good outline drawings, to show form, structure etc., are preferable, but sometimes shading can be used to good advantage. It is suggested that the upper 2/3 of a sheet be used for the drawings, which should be neatly made and lettered, and the lower part of the page be used for the brief descriptions, or names of the parts. The fuller notes and descriptions of the plant, or process, or record of the experiment should be made on another sheet, using one, two, three, or more sheets where necessary. Notes and drawings should be made only on one side of the sheet. The note-sheets and the drawing-sheets for a single study, as a single experiment, should be given the same number, so that they can be bound together in the cover in consecutive order. Each experiment may be thus numbered, and all the experiments on one subject then can be bound in one cover for inspection by the instructor. For example, under protoplasm, spirogyra may be No. 1, mucor No. 2, and so on. In connection with the practical work the book can be used by the student as a reference book; and during study hours the book can be read with the object of arranging and fixing the subject in the mind, in a logical order.

The instructor should see that each student follows some well-planned order in the recording of the experiments, taking notes, and making illustrations. Even though a book be at hand for the student to refer to, giving more or less general or specific directions for carrying on the work, it is a good plan for every teacher to give at the beginning of the period of laboratory work a short talk on the subject for investigation, giving general directions. Even then it will be necessary to give each individual help in the use of instruments, and in making preparations for study, until the work has proceeded for some time,

when more general directions usually answer. The author does not believe it a good plan for the student to have written, minute, directions for preparing the plants and experiments. General directions and specific help where there is difficulty, until the student learns to become somewhat independent, seems to be a better plan.

APPARATUS AND GLASSWARE.

The necessary apparatus should be carefully planned and be provided for in advance. The microscopes are the most expensive pieces of apparatus, and yet in recent years very good microscopes may be obtained at reasonable rates, and they are necessary in any well-regulated laboratory, even in elementary work.

Microscopes. The number of compound microscopes will depend on the number of students in the class, and also on the number of sections into which the class can be conveniently divided. In a class of 60 beginning students I have made two sections, about 30 in each section; and 2 students work with one microscope. In this way 15 microscopes answer for the class of 60 students. It is possible, though not so desirable, to work a larger number of students at one microscope. Some can be studying the gross characters of the plant, setting up apparatus, making notes and illustrations, etc., while another is engaged at the microscope with his observations.

The writer does not wish to express a preference for any pattern of microscope. It is desirable, however, to add a little to the price of a microscope and obtain a convenient working ou . For example, a fairly good stand, two objectives (2/3 and 1/6), one or two oculars, a fine adjustment, and a coarse adjustment by rack and pinion, and finally a revolver, or nosepiece, for the two objectives, so that both can be kept on the microscope in readiness for use without the trouble of removing one and putting on another. Such a microscope, which I have

found to be excellent, is Bausch & Lomb's AAB (which they recommend for high schools), costing about $25.00 to $28.00. I have compared it with some foreign patterns, and the cost of these is no less, duty free, for an equivalent outfit. Of course, one can obtain a microscope for $18.00 to $20.00 without some of these accessories, but I believe it is better to have fewer microscopes with these accessories than more without them. Of the foreign patterns the Leitz (furnished by Wm. Krafft, 411 W. 59th St., N. Y.) and the Reichert are good, while Queen & Co., Philadelphia, Pa., and Bausch & Lomb, Rochester, N. Y., furnish good American instruments.

Glass slips, 3 × 1 inch; and circle glass covers, thin, 3/4 in. diameter.

Glass tubing of several different sizes, especially some about 5*mm* inside diameter and 7*mm* outside measurement, for root-pressure experiments.

Rubber tubing to fit the glass tubing, and small copper wire to tighten the joints.

Watch glasses, the Syracuse pattern (Bausch & Lomb), are convenient.

U tubes, some about 20*mm* diameter and 10–15*cm* long. Corks to fit.

Small glass pipettes ("medicine droppers") with rubber bulbs.

Wide-mouth bottles with corks to fit. Reagent bottles. (Small ordinary bottles about 10*cm* × 4*cm* with cork stoppers will answer for the ordinary reagents. The corks can be perforated and a pipette be kept in place in each ready for use. Such bottles should not be used for strong acids.)

Small vials with corks for keeping the smaller preparations in.

Small glass beakers or tumblers.

A few crockery jars for water cultures.

Fruit jars for storing quantities of plant material.

Glass graduates; 1 graduated to 1000*cc*, 1 graduated to 100*cc*.

Funnels, small and medium (6 and 10*cm* in width). Test

tubes. A few petrie dishes. Bell jars, a few tall ones and a few low and broad. Thistle tubes. Chemical thermometer.

Balance for weighing. A small hand-scale furnished by Eimer & Amend, 205–211 3d Ave., N. Y., is fairly good ($2.00).

For pot experiments, the "Harvard trip-scale," Fairbanks Scale Co. (about $6.00).

Apparatus stand, small, several, with clamps for holding test tubes, U tubes, etc.

Agate trays, very shallow, several centimeters long and wide. Agate pans, deep, for use as aquaria, etc., with glass to cover.

Paraffin or wax, for sealing joints in setting up transpiration apparatus.

Mercury, for restoration of turgidity, and for lifting power of transpiration.

Sheet rubber, or prepared vessels for enclosing pots to prevent evaporation of water from surface during transpiration experiments.

Litmus paper, blue, kept in a tightly stoppered bottle. Filter paper for use as absorbent paper. Lens paper (fine Japanese paper) for use in cleaning lenses; benzine for first moistening the surface, and as an aid in cleaning.

For materials for culture solution, see Chapter III.

Reagents.

Glycerine, alcohol of commercial (95%) strength, formalin or formalose of 40% strength, chloral hydrate crystals, iodine crystals, eosin crystals, fuchsin crystals, potassium iodide, potassium hydrate, potash alum. It is convenient also to have on hand some ammonia, sulphuric acid, nitric acid, and muriatic acid in small quantity.

Reagents ready for use and for storing plant material in.

Alcohol. Besides the 95% strength, strengths of 30%, 50%, and 70%, for killing material and bringing it up to 70% for storage.

Formalin. Usually about a 2½% is used for storing material, made by taking 97½ parts water in a graduate and filling in 2½ parts of the 40% formalin.

Salt solution 5%; sugar solution 15% (for osmosis).

Iodine solution. Weak—to 300*cc* distilled water add 2 grams iodide of potassium; to this add 1 gram iodine crystals.

Strong—use less water.

Eosin. Alcoholic solution. Distilled water 50*cc*, alcohol 50*cc*, eosin crystals ½ gram, potash alum 4 grams.

Aqueous solution. Distilled water 100*cc*, eosin crystals 1 gram.

Chloral hydrate; aqueous solution, nearly sat. sol.

Schimper's solution. Chloral hydrate 5 parts, water 2 parts, iodine to make a strong color.

Student list of apparatus.

Several glass slips 3 × 1 inch, and more circle glass covers, thin and ¾ inch diameter.

One scalpel.

One pair forceps, fine points.

Two dissecting needles (may be made by thrusting with aid of pincers a sewing needle in the end of a small soft pine stick).

Lead-pencils, one medium and one hard.

Note paper; a good paper, about octavo size, smooth, unruled, with two perforations on one side for binding. Several manila covers or folders to contain the paper, perforated also. Enough covers should be provided so that notes and illustrations on different subjects can be kept separate.

REFERENCE BOOKS.

The following books are suggested as suitable ones to have on the reference shelves, largely for the use of the teacher, but sev-

eral of them can with profit be consulted by the students also. There are a number of other useful reference books in German and French, and also a number of journals, which might be possessed by the more fortunate institutions, but which are too expensive for general use, and they are not listed here.

Kerner and Oliver, Natural History of Plants. Blackie & Son, London, 1895. Henry Holt & Co., New York, 1895.

Strasburger, Noll, Schenck & Schimper, A Text Book of Botany, translated by Porter. The Macmillan Co., New York, 1898.

Vines, Student's Text Book of Botany. The Macmillan Co., New York, 1895.

Atkinson, The Biology of Ferns. The Macmillan Co., New York, 1894.

MacDougal, Experimental Plant Physiology. Longmans, Green & Co., New York.

Spalding, Introduction to Botany. D. C. Heath & Co., Boston, 1895.

Bessey, Essentials of Botany. Henry Holt & Co., New York.

Goebel, Outlines of Classification and Special Morphology of Plants. Oxford, Clarenden Press, 1887.

Warming & Potter, Hand Book of Systematic Botany. Macmillan & Co., New York, 1895.

DeBary, Comparative Morphology and Biology of the Fungi, Mycetozoa, and Bacteria. Oxford, Clarenden Press, 1887.

Underwood, Our Native Ferns and their Allies. Henry Holt & Co., New York.

Bailey, Lessons in Plants. Macmillan & Co., New York, 1898.

Gray, Lessons and Manual of Botany. American Book Co., New York.

Müller, The Fertilization of Flowers. Macmillan & Co., New York.

Darwin, Insectivorous Plants. D. Appleton & Co., New York.

Darwin, The Power of Movement in Plants. D. Appleton & Co., New York.

Darwin, Cross and Self Fertilization in the Vegetable Kingdom. D. Appleton & Co., New York.

Warming, Oekologische Pflanzengeographie. Gebrüder Bornträger, Berlin.

Campbell, A University Text-book of Botany. The Macmillan Co., New York, 1902.

Schimper, Plant Geography on a Physiological Basis. English translation, W. R. Fisher, revised and edited by P. Groom and I. B. Balfour, Oxford, 1903.

Papers by Macmillan and others in the Bulletin of the Torrey Botanical Club, and Minn. Bot. Studies, by Shaler, in the 6th, 10th, and 12th Ann. Repts. of the United States Geological Survey; by Ganong, Cowles, and others in the Botanical Gazette.

In a pamphlet of 67 pages, being an outline of a course of lectures on the relation of plants to environment by Geo. F. Atkinson, there are nine pages devoted to bibliography.

Where materials cannot be readily collected in the region for class use, they can often be purchased of supply companies.

The Plant Study Co. and the Cambridge Botanical Supply Co., of Cambridge, Mass., supply plant material of several groups for study, as well as apparatus and paper.

The St. Louis Biological Laboratory also supplies plants, and especially prepared slides of microscopic preparations, as well as lantern slides.

INDEX.

Absorption, 13, 22–28
Acclimatization, 469
Aceraceæ, 685, 707
Acer saccharinum, 685
Acorn, 451
Acorus calamus, 662, 703
Adansonia, 534
Æcidiomycetes, 218
Æcidiospore, 189
Æsculus hippocastanum, 686, 707
Agaricaceæ, 199, 219
Agaricus arvensis, 206
Agaricus campestris, 200–207
Agave, 560
Agropyron dasystachyum, 592, 594
Agropyron pseudorepens, 561, 563
Agropyron tenerum, 590
Agrostis hiemalis, 602
Akene, 451
Albumen, 98
Albuminous, 98, 108
Alder, 704
Algæ, 136–176, 589, 653
Algæ, absorption by, 22
Alismaceæ, 702
Alkaline basins, 618
Almond family, 680
Alpine formation, 516, 526
Alpine plant societies, 582–585
Alum-root, 602
Amanita phalloides, 207, 208
Amaranth, 705
Amaryllidaceæ, 703
Aments, 429
American mistletoe, 705
Ammophila arenaria, 592, 599
Ammophila arundinacea, 594
Ampelopsis, 708
Ancylistales, 215
Andreales, 249
Androecium, 319, 419
Andromeda polifolia, 609
Andropogon furcatus, 559, 561
Andropogon scoparius, 559, 561
Anemophilous, 435
Angiosperms, morphology of, 318–348
Angiosperms, representative families, 648–701
Antennaria campestris, 562
Antheridiophore, 227
Antheridium, 144, 149, 155, 176, 223, 228, 240, 245, 246, 266, 287, 433
Anthesis, 429
Anthoceros, 240, 241
Anthocerotales, 242
Anthocerotes, 242
Apogamy, 346
Apogeotropic (ap″o-ge″o-trop′ic), 126
Apogeotropism (ap″o-ge-ot′rō-pism), 126
Apple, 456, 681, 706
Apple family, 680, 706
Aquatic formations, 521, 526
Aquatic plant societies, 620–629
Araceæ, 662, 703
Archegonia (ar-che-go′ni-a), 223, 229, 233, 241, 244–246, 267, 288, 291, 307–308
Archegoniophore, 229
Archegonium, 433
Archesporium (ar″che-spo′ri-um), 235
Archidiales, 249
Arctic formation, 516, 526, 576–582
Arenaria stricta, 602
Aril, 457
Arisæma, 662–666, 703
Arisæma triphyllum, 442, 443
Aristolochiales, 705
Arrow leaf, 625, 626, 702

Artemisia canadensis, 590, 591
Artemisia caudata, 590, 591
Artemisia spinescens, 572
Artemisia tridentata, 559, 570
Arum family, 662, 703
Arundinaria, 538, 617
Asclepias, 710
Asclepias cornuti, 462
Ascomycetes (as-co-my-ce'tes), 195–198, 216–218
Ascophyllum nodosum, 622, 629
Ascus, 190, 213
Ash of plants, 79, 80
Ash tree, 710
Aspidium acrostichoides, 253, 257
Assimilation, 67, 109
Aster, 712
Aster novæ-angliæ, 697–700
Atoll moor, 611–615
Atriplex, 563, 572, 705
Atriplex canescens, 570
Atriplex confertifolia, 572
Auriculariales, 218
Austral forests, 535
Autotrophic plants, 85
Autumn colors, 535
Autumnal flora, 562
Azalea, 709
Azolla, 296, 627

Bacteria, 164, 165, 623, 624, 626
Bacteria, nitrite and nitrate, 83
Bacteriales, 164, 165
Bacteroid, 93
Bad Lands, 562
Bald cypress, 537, 538
Bangiales, 175
Banyan tree, 533
Basidiomycetes (Ba-sid"i-o-my-ce'-tes), 199–208, 218
Basidium, 201, 213
Bassweed, 625, 626
Bast, 50–52
Batrachospermum, 171–173, 175
Bazzania, 25
Beard grasses, 559, 561
Bedstraws, 711
Beechnut, 452
Beet, osmose in, 15, 16, 17, 18
Begonia, 407
Bellflower, 711
Benthos, 621
Berry, 454, 455, 456
Betulaceæ, 704
Bicuculla, 706
Bidens, 458
Bignonia, 711
Big trees, 538–541
Bilberries, 709
Biothermal lines, 501, 503
Biotic factors, 479, 509
Birch, 704
Bird's-nest fungi, 220
Blackberry, 454
Black fungi, 198
Bladderwort, 610, 711
Blasia, 164, 236
Bloodroot, 706
"Blowouts," 599, 561
Bluets, 436, 437, 602, 711
Boletus, 209
Boletus edulis, 209
Boraginaceæ, 710
Boreal forests, 534
Botrychium, 295
Botrydiaceæ, 162
Botrydium granulatum, 146, 162
Bouteloua oligostachya, 559, 562
Broom sedge, 559
Brown algæ, 628; uses of, 170
Bryales, 349
Bryophyta (Bry-oph'y-ta), 653
Bud sage, 572
Buds, winter condition of, 374–377
Buckeye family, 686, 707
Buckthorn, 708
Buckwheat, 705
Buffalo-grass, 559
Bug seed, 563, 705
Bulb, 372
Bulbilis dactyloides, 559
Bulrushes, 606, 625
Bunch-grasses, 559, 561
Burr-grass, 590
"Bush," 516
Buttercup, 676
Butternut, 452, 670, 704
Butterwort, 610
Buttes, 562, 563
Buttonbush, 711
Buttonwood, 706

Cacti, 395, 559, 560, 566, 570–573, 708
Cakile edentula, 590
Cakile fusiformis, 590
Calamagrostis longifolia, 594
Calamovilfa brevipilis, 592
Calla palustris, 662

Callithamniom, 173
Calluna vulgaris, 616
Calyptrogen, 361
Cambium, 50, 52, 358, 363
Campanula rotundifolia, 442, 444, 601, 711
Campanulales, 697, 711
Cane swamp, 617
Canna, 445–449, 703
Capsella bursa-pastoris, 676, 706
Capsule, 453
Carbohydrate, 71, 75, 80, 90
Carbon dioxide, 62–67, 110–113
Cardinal flower, 711
Cardinal temperature points, 468, 469
Carex, 607
Carex filiformis, 611
Carex laxiflora, 661
Carex lupulina, 660
Carpogonium, 172, 176
Caryophyllaceæ, 705
Caryopsis, 451
Cassia marilandica, 402
Cassiope, 395, 580
Cassiope tetragona, 610
Castalia odorata, 627, 705
Castor-oil plant, 707
Catalpa, 711
Catkin, 428
Catnip, 695
Cattail-flag, 702
Caulerpa, 628
Caulidium, 371
Cedar apples, 194
Cedar of Lebanon, 406
Cell, 3; artificial, 20
Cell sap, 3, 40
Cenchrus macrocephalus, 590
Ceratopteris thalictroides, 296
Cereus, 560
Chætophora, 151, 162
Chætophoraceæ, 162
Chaparral, 530, 531
Chara, 176, 625, 626
Charales, 176
Chemical condition of soil, 473
Chemosynthetic assimilation, 109
Chenopodiales, 705
Chenopods, 563, 564, 705
Chestnut, 452, 704
Chestnut trees, 534
Chicory family, 700, 711
Chlamydomonas, 159, 160
Chlamydospores, 180
Chloral hydrate, 65, 87
Chlorophyceæ, 158
Chlorophyll, 2, 67, 72
Chloroplast, 68, 69, 71
Christmas fern, 251–253
Chromoplast, 71
Chromosomes, 342–345
Chroococcaceæ, 163
Chrysanthemum, 712
Chytridiales, 215
Cichoriaceæ, 700, 711
Cichorium intybus, 711
Cladophora, 626, 627
Clavaria botrytes, 212
Clavariaceæ, 210, 219
Claytonia virginica, 705
Cleistogamous, 435
Clematis virginiana, 462, 463, 674, 675, 706
Climatic factors, 477
Climatic formations, 514–518
Climatic pressures, 510, 512
Clostridium pasteurianum, 93
Clover, 707
Club mosses, 284, 289
Cnicus pitcheri, 591
Coccogonales, 163
Cocklebur, 711
Cold wastes, 516
Coleochætaceæ, 162
Coleochæte, 153–156, 226, 626
Collenchyma, 356, 363
Comandra, 705
Compass plants, 409
Compositæ, 697, 712
Comptonia asplenifolia, 704
Cone fruit, 456
Confervoideæ, 162
Coniferæ, 316
Conjugation, 137, 141, 160, 162, 179
Convallariaceæ, 703
Cooperia, 703
Cordyceps, 218
Coreopsis, 712
Corispermum hyssopifolium, 536, 590
Cork, 357, 363
Corm, 373
Cornus stolonifera, 594
Cortex, 50
Corymb, 427
Cotton-grass, 617
Cottonwood, 592

Cotyledon, 99–101
Cranberry, 709
Cratægus, 707
Crowfoot family, 673, 706
Cruciferæ, 652, 676, 706
Cryptonemiales, 175
Cucurbitaceæ, 711
Culture formations, 521, 526
Cultures, water, 28, 29
Cup fungi, 199
Cupuliferæ, 669, 704
Cuscuta, 83, 710
Cushion type of vegetation, 584–585
Cuticle, 43
Cyanophyceæ, 163, 589, 622, 624
Cyatheaceæ, 295
Cycadales, 316
Cycas, 311, 312, 457
Cyclosis, 9, 10
Cyclosporales, 171
Cyme, 430, 432
Cyperaceæ, 659, 702
Cyperus, 607
Cypress, 534, 537, 491
Cypripedium, 443, 447, 666, 703
Cystocarp, 174
Cystopteris bulbifera, 260
Cystopus, 215
Cytase, 92, 108
Cytisus, 445
Cytoplasm (cy'to-plasm), 5

Dacryomycetales, 219
Dahlia, 108
Dandelion, 700, 711
Dasiphora fruticosa, 619, 706
Daucus carota, 691, 692, 708
Death's valley, 568
Dehiscence, 453
Dentaria, 322–324, 676
Dentaria diphylla, 652, 653, 706
Dermatogen, 359
Desert formation, 517, 526
Desert plant societies, 565–575
Desmodium, 458
Desmodium gyrans, 399
Diadelphous (di''a-del'phous), 425
Diageotropism (di''a-ge-ot'ro-pism), 126
Diaheliotropic (di''a-he''li-o-trop'-ic), 127
Diaheliotropism (di''a-he''li-ot'ro-pism), 127
Diastase, 77, 78, 108, 116
Diatoms, 166, 622, 626
Dichogamous (di-chog'a-mous), 437, 442
Dicentra, 706
Dicotyledons, 651, 652, 667–701, 704
Dictyophora, 219
Diffusion, 13–20
Digestion, 107, 108, 109
Dimorphism of ferns, 273–280
Dicecious, 435
Dionæa muscipula, 133, 611
Dipodascus, 216
Dipsacus, 711
Discomycetes, 217
Distichlis, 563
Distribution, 497
Dodder, 83, 84, 710
Dogwood, 708, 709
Dondia linearis, 590
Dothidiales, 218
Downy mildews, 185
Drosera, 706
Drosera rotundifolia, 133
Drupaceæ, 680, 707
Drupe, 454
Duck meat, 627
Duckweeds, 26, 28, 627, 665
Dudresnaya, 175
Dune-forming plants, 593, 594
Dunes, kinds of, 592, 593; methods of checking, 598, 599; vegetation of, 592–599
Dysphotic region, 621

Eatonia obtusata, 559
Ebenales, 710
Ecological factors, 464, 465
Ecology (sometimes written œcology), 464
Ectocarpus, 167
Edaphic formations, 518, 526, 560
Elaphomyces, 217, 218
Elder, 711
Elm family, 672, 704
Elodea, 61–63
Elymus canadensis, 561, 590, 594
Embryo of ferns, 269–272
Embryo sac, 326–328
Empusa, 215
Endocarp, 450
Endomyces, 216
Endosperm, 103, 105, 107, 306, 309, nucleus, 327, 329–334
Enteromorpha, 628

Entomophthorales, 215
Enzyme, 92, 98, 116, 117
Epidermal system, 358
Epidermis, 358, 359, 363
Epigæa repens, 709
Epigynous, 425
Epilobium, 708
Epinastic (ep-i-nas'tic), 129
Epinasty (ep'i-nas-ty), 129
Epipactis, 444, 447, 665
Epiphegus, 84
Epiphytes, 416, 544, 621
Equisetales, 296
Equisetineæ, 296
Equisetum, 280–283
Ericaceæ, 709
Ericales, 709
Erythronium, 649, 654, 703
Etiolated plants (e'ti-o-la"ted), 68
Euascomycetes, 217
Eubasidiomycetes, 219
Eupatorium, 403, 712
Euphorbia polygonifolia, 590, 592
Euphorbiaceæ, 707
Eurotia lanata, 572
Eurotium oryzæ, 78
Evening primrose family, 689–708
Exalbuminous, 108
Exoascus, 217
Exobasidiales, 219
Exocarp, 450

Facies, 525
Fagales, 669, 704
Fehling's solution, 75, 76, 712
Ferment, 98, 108, 116
Fern, "walking," 508, 509
Ferns, 251–279, 292, 457; classification of, 295; of rocky places, 601
Fertilization, 307, 308, 328, 329, 140, 145, 169, 172, 174, 197, 421
Fibrovascular bundles, 49–54
Figwort family, 696, 710
Filicales, 295
Filicineæ, 295
Fittonia, 404
Flagellates, 83, 165
Flax, 707
Flora, 497
Flower cluster, 419
Flower, form of, 422; parts of, 419; union of parts, 424
Flowers, arrangements of, 426; kinds of, 421
Follicle, 453
Fontinalis, 626, 627
Forest, 516; enemies of, 552; formations, 560; longevity of, 531; protection, 551; regeneration, 548–552; societies, 529–555; structure of, 531
Forests, relation to rainfall, 546
Formations, aquatic, 625–629; study of, 630–647
Fragaria vesca, 680
Fraxinus americana, 602
Freezing, 470
Fresh-water societies, 624
Frond, 352
Fruit, 450–457, 507; parts of, 450
Frullania, 25, 236
Fucus, 168–170, 622
Fungi, 653; absorption by, 22; classification of, 213–222; nutrition of, 86–90; respiration in, 115

Gametangium (gam"et-an'gi-um), 140
Gamete (gam'ete), 138, 139
Gametophore (gam'et-o-phore), 230, 248
Gametophyte (gam'et-o-phyte), 225, 226, 244, 245, 250, 262, 270, 283, 292, 294, 305, 314, 317, 336–339, 340–348, 434
Gamopetalous (gam"o-pet'a-lous), 424
Gamosepalous (gam-o-sep'a-lous), 424
Gas in plants, 60–64
Gasteromycetes, 219
Gemmæ, 179, 235
General formations, 526
Gentian, 710
Geotropism (ge-ot'ro-pism), 125–127, 410
Geraniaceæ, 677, 707
Geraniales, 676, 707
Geranium family, 677, 707
Germ, 459
Gigartinales, 175
Gingko, 313–315, 457
Gingkoales, 316
Ginseng, 708
Glaciers, influence of, 510–511
Glasswort, 563, 705
Gleicheniaceæ, 295
Glucose, 108. See sugar.

Gnetales, 316
Gonidia, 118, 143, 172, 174, 178–184
Gonidiangium (go″nid-an′gi-um), 178
Gonidium, 213
Gooseberry, 706
Goosefoot family, 705
Gracilaria, 173, 174, 175
Grama grass, 559, 562
Graminales, 657, 702
Gramineæ, 657, 702
Grape, 708
Grass family, 657, 702
Grasses, 607, 625
Grassland formation, 517, 526, 556
Greasewoods, 564
Green algæ, 158, 628
Ground covers, 471
Growth, 118–124, 380
Gulfweed, 170
Gymnosperms, 311, 456, 653
Gymnosporangium, 194
Gynœcium, 320, 419, 451, 452
Gyrocephalus, 219

Halophytes, 484, 563, 619, 621
Halophytic structures, 495
Harebell, 601
Harpochytrium, 214, 215

Haustorium, 87, 88
Hawkweed, 700, 711
Hawthorn, 707
Hazelnut, 452, 704
Head, 428
Heart leaf, 705
Heat, 468, 504, 505
Heath family, 709
Heath moors, 578, 616
Heather, 616
Heliotrope, 710
Heliotropism (he-li-ot′ro-pism), 127–131, 133, 397
Helvellales, 217
Hemiascomycetes, 216
Hemibasidiomycetes, 218
Hepaticæ, 242
Heteranthera, 627
Heterospory (het″er-os′po-ry), 434
Heterothallic, 180
Heterotrophic plants, 85
Heuchera americana, 602
Hickory, 704
Hickory nut, 452

Hieraceum venosum, 700
Hilum, 101, 102
Hippocastanaceæ, 686, 707
Holdfasts, 418
Hollyhock, 708
Homothallic, 180
Honeysuckle, 711
Hormogonales, 163
Horse-chestnut, 686, 707
Horsetails, 280–283
Hot springs, vegetation of, 624
Houstonia cærulea, 437; purpurea 601; Houstonia, 711
Huckleberry, 709
Humus saprophytes, 85, 91, 709
Hybridization, 338
Hydnaceæ, 210, 219
Hydnum coralloides, 210
Hydnum repandum, 211
Hydrocarbon, 75
Hydrodictyaceæ, 161
Hydrodynamic forces, 467
Hydrophytes, 484, 620, 621
Hydrophytic structures, 490
Hydropterales, 295
Hydrotropism (hy-drot′ro-pism), 133, 134, 412
Hygrophytes, 485
Hymeniales, 219
Hymenogastrales, 219
Hymenomycetes, 219
Hymenomycetineæ, 219
Hymenophyllaceæ, 295
Hypericum, 708
Hypocotyl (hy′po-co″tyl), 101
Hypocreales, 217
Hypogenous, 425
Hyponastic (hy-po-nas′tic), 129
Hyponasty (hy′po-nas-ty), 129
Hysteriales, 217

Impatiens, 707
Impatiens fulva, 460
Indian-grass, 559
Indian-pipe, 709
Indian-turnip, 662, 703
Individual formations, 522–524, 526
Indusium, 252
Inflorescence, 426
Insectivorous plants, 133, 610, 611, 706
Integument, 304
Intramolecular respiration, 113, 114
Inulase, 108

Inulin, 108, 417
Iodine, 65
Ipomœa, 710
Ipomœa acetosæfolia, 590
Ipomœa pes-capræ, 590, 592
Iridaceæ, 703
Iris, 703
Irritability, 125–135
Isoetales, 296
Isoetes, 289–291, 292, 627
Isoetineæ, 296
Iva imbricata, 599
Ivy, 708

Jack-in-the-pulpit, 373
Jewelweed, 707
Juglandales, 704
June-berry, 707
Jungermanniales, 242

Kalmia latifolia, 444
Karyokinesis, 341–344
Kelps, 168
Kingdom, 653
Kochia americana, 572
Koehleria cristata, 559

Labiatæ, 423, 694, 710
Laboulbeniales, 218
Labrador tea, 609, 709
Lactuca canadensis, 460
Lactuca scariola, 409, 460, 461
Lagenidium, 214, 215
Laminaria, 168, 169, 628
Lamium, 424, 694, 710
Larch, 367
Lathyrus maritimus, 592
Laurel, 709
Layers, 525
Leaf patterns, 404
Leather leaf, 609
Leathesia difformis, 168
Leaves, form and arrangement, 383–391; function of, 387; protective modifications of, 392; protective positions, 395; reduction of surface, 394; relation to light, 397; structure of, 40–43, 131, 391, 393
Legumes, 92, 93, 453
Leguminosæ (= Papilionaceæ), 396, 399
Leitneria floridana, 704
Leitneriales, 704
Lemanea, 171, 173, 175, 492, 623, 626, 627
Lemna, 418, 627
Lemna trisulca, 26, 27
Lenticel, 357, 358
Lepiota naucina, 208
Lettuce, 711
Leucoplast, 71
Liana, 545
Lichen tundra, 579
Lichens, 86, 93–95, 220, 221, 578; formations on rocks, 600–603
Life areas, 500–504
Life regions, 500–504
Life zones, 500–504, 641–647
Light, 467
Light, regions of, in water, 621
Liliaceæ, 650–652, 654, 703
Liliales, 651, 652, 654, 703
Lilium, 650, 703
Limnetic plant societies, 624–627
Linaria vulgaris, 696, 711
Linden, 708
Linum vulgaris, 707
Lipase, 108
Liquidambar, 706
Liriodendron, 706
Lithophytes, 621
Live-forever, 394
Liverworts, 222–239, 653; absorption by, 23–25; classification of, 242
Lobelia, 711
Lupinus perennis, 353
Lycoperdales, 220
Lycopodiaceæ, 296
Lycopodiales, 296
Lycopodiineæ, 296
Lycopodium, 284–286

Macrophytes, 622
Macrosporangium, 94, 302, 304, 311, 312, 321
Macrospore, 287, 290, 326–328, 434
Magnolia, 705, 706
Mallow family, 708
Malvales, 708
Mangrove swamps, 538, 618
Maple family, 685, 707
Marchantia, 24, 226–236
Marchantiales, 242
Marine plant societies, 627–629
Maritime ruppia, 618
Marl ponds, 619, 624

Marram grass, 592, 599
Marratiales, 295
Marsilia, 370, 625, 627
Marsiliaceæ, 296
Marshes, alkaline, 563
Matoniaceæ, 295
Meadow swamps, 607
Meadows, 561, 628
Medicago denticulata, 92
Medulla, 50
Members of the flower, 335
Members of the plant, 349–353
Meristem, 359
Mesocarp, 450
Mesophytes, 483, 485, 493
Mesophytic structures, 492
Mesquite, 560
Microphytes, 621
Microsporangia, 294, 299
Microspore, 287, 290, 299, 312, 435
Microsporophylls, 299, 320, 420
Migration, barriers to, 513; causes of, 506, 509–513; laws of, 497; lines of, 500
Milkweed, 462
Milkweed family, 710
Mimosa, 132, 396
Mimulus, 710
Mint family, 694, 710
Mistletoe, 84, 705
Mitchella, 711
Mixotrophic plants, 85
Mnium, 243–246
Molds, nutrition of, 86–90
Molds, water, 181
Monadelphous, 424
Monoblepharidales, 215
Monoblepharis, 215
Monocotyledons, 651–666, 702
Monœcious, 435
Monotropa uniflora, 709
Morchella, 198, 199
Morel, 198, 199
Morning-glories, 590, 710
Mosaics, 405
Moss tundra, 578
Mosses, 243–248, 457, 584, 653; absorption by, 25; classification of, 248
Mucor, 6, 7, 15, 118, 119, 177–180, 215
Mucorales, 215
Mud swamp, 606
Mulberry, 704
Mullein, 366, 394, 710
Mushrooms, 199–208, 552–555
Muskeag, 607
Mustard family, 676, 706
Mutation, 338
Mutualism, 95
Mycelium, 6, 86–90
Mycetozoa, 213, 214
Mycorhiza, 86, 91, 92, 217
Myosotis, 710
Myrica cerifera, 704
Myrica gale, 704
Myricales, 704
Myriophyllum, 403
Myrtales, 689, 708
Myxobacteriales, 165
Myxomycetes, 83, 213, 214

Naiadaceæ, 702
Naiadales, 702
Naias, 627, 702
Nemalion, 171, 172, 175
Nemalionales, 175
Nepeta cataria, 695
Nettle, 704
Nicotiana, 710
Nidulariales, 220
Nitella, 8, 9, 176
Nitrobacter, 83
Nitrogen, 92, 93
Nitromonas, 83
Nostoc, 589
Nostocaceæ, 164
Nucellus, 304
Nucleus, 3, 4; morphology of, 340–345
Nuphar advena, 627, 705
Nutation, 123, 124
Nymphæa odorata, 627, 705

Oak, 669–671, 704
Oak family, 669, 704
Oases, warm, 581
Œdogoniaceæ, 162
Œdogonium, 147–151, 350, 626
Œnothera biennis, 592, 690, 708
Œnothera gigas, 338
Œnothera lamarkiana, 338
Olpidium, 214, 215
Onagra biennis, 708
Onagraceæ, 689, 708
Onoclea sensibilis, 254, 273–278
Oogonium, 144, 150, 155
Oomycetes, 214, 215
Ophioglossales, 295
Ophioglossum, 295

Opuntia, 559
Opuntiales, 708
Orchidaceæ, 665, 703
Orchidales, 665, 703
Orchids, 442
Oscillatoria, 589
Oscillatoriaceæ, 163
Osmosis, 13–20
Osmundaceæ, 295
Ostrich fern, 279
Ovule, 302, 321, 334, 421
Oxalis, 707
Oxycoccus, 709
Oxydendrum arboreum, 709
Oxygen, 63, 110–113

Pacific forests, 538
Palisade cells, 41, 43
Palmaceæ, 702
Palmales, 702
Palms, 408
Palustrine forest, 537
Pandanales, 702
Panicum scribnerianum, 559
Pandanus, 702
Pandorina, 160, 350
Panicle, 427
Panicum amarum, 599
Panicum halophilum, 599
Panicum repens, 599
Papaverales, 652, 676, 706
Papilionaceæ, 423, 682, 707
Parasites, 83, 84, 86, 527, 628
Parasitic fungi, nutrition of, 86–90
Parenchyma, 50, 356, 363
Parietales, 687, 708
Parkeriaceæ, 296
Parmelia, 96
Parmelia contigua, 602
Parsley family, 692; =carrot family, [708
Parthenogenesis, 184
Partridge berry, 711
Pea, 683, 707
Pea family, 682, 707
Pear, 456, 682
Peat moors, 578, 607
Peat moss, 608
Pediastrum, 161
Pelagic plant societies, 627–629
Pellia, 164
Pellonia, 405
Peltigera, 94, 95
Pepo, 456
Pericycle, 360
Peridineæ, 166
Perigynous, 425
Perisperm, 331, 332
Perisporiales, 217
Peronospora, 183, 215
Peronosporales, 215
Persimmon, 710
Peucedanum fœniculaceum, 562
Peucephyllum schattii, 571
Pezizales, 217
Phacidiales, 217
Phæophyceæ, 167
Phæosporales, 171
Phallales, 219
Phloem, 50–52, 360, 361, 363
Phlox family, 710
Phoradendron flavescens, 84, 705
Photic region, 621, 628
Photosynthesis, 67, 68, 70, 117, 622
Phycomycetes (Phy"co-my-ce'tes), 214, 215
Phyllidium, 371
Phylloclades, 373, 395
Phyllotaxy, 375, 384
Physical condition of soil, 475, 476
Physical factors, 465–476
Physiography, 479
Phytolaccaceæ, 705
Phytomyxa leguminosarum, 92
Phytophthora, 182, 184, 215
Pickerel weed, 626, 703
Pilularia, 296, 627
Pinales, 216, 653
Pine, white, 297–310
Pinguicula vulgaris, 610
Pinus divaricatus, 602
Pinus scopularum, 560
Pinus strobus, 602, 653
Piperales, 704
Pisum sativum, 683
Pitcher-plant, 610, 706
Pith, 50
Plains' formations, 559
Plankton, 621
Plant-food, sources of, 81
Plant-formations, 515–528
Plant-substance, analysis of, 79, 80
Plantaginales, 711
Plantago, 711
Plasmolysis (plas-mol'y-sis), 19
Plasmopara, 183, 215
Plectascales, 217
Plectobasidiales, 220
Pleurococcaceæ, 161

Pleurococcus, 161
Plum family, 680, 707
Plumule, 99
Podostemon, 626, 627, 706
Poison-hemlock, 708
Poison-ivy, 707
Poison-oak, 707
Poisonous mushrooms, 207, 208
Poison-sumac, 707
Pokeweed, 705
Polemoneales, 694, 710
Pollen-grain, 299, 305
Pollination, 303, 304, 420, 430, 433–449, 479
Pollinium, 420
Polygonales, 705
Polygonum, 705
Polypodiaceæ, 296
Polyporaceæ, 209, 219
Polyporus, 209, 210
Polyporus mollis, 90
Polyporus sulphureus, 209
Pomaceæ, 680, 706
Pond-lilies, 625, 626
Pondweeds, 626, 702
Poppy, 705
Populus balsamifera, 592, 594
Populus monolifera, 592, 594
Populus tremuloides, 602
Porella, 237
Portulaca, 705
Postelsia, 492.
Potamogeton, 702
Potamogeton natans, 625, 627
Potato, 710
Potentilla fruticosa, 619
Powdery mildews, 195–198, 217
Prairie formations, 557
Prairie societies, 556–560
Primrose, 708, 710
Primula, 438
Primulales, 710
Principal formations, 522, 526
Procarp, 172, 174, 175
Progeotropism (pro"ge-ot'ro-pism), 126
Promycelium (pro" my-ce'li-um), 192
Prosopis juliflora, 560
Protection to plants, 471–473
Proterandrous, 441, 442
Proterandry, 444
Proterogenous, 441, 442
Proterogeny, 440
Prothallium, 265, 287, 288, 291, 292, 304, 305, 311, 325, 328, 335, 433, 434
Protoascales, 216
Protoascomycetes, 216
Protobasidiomycetes, 218
Protococcoideæ, 158, 621
Protodiscales, 217
Protomyces, 216
Protonema (pro"to-ne'ma), 248, 264
Protoplasm, 1–12, 42–43, 342; movement of, 7–11
Prunus pumila, 590, 594
Prunus virginiana, 681
Psilotaceæ, 296
Pteridophyta (Pter"id-oph'y-ta), 653
Pteridophytes, 295, 434
Pteris cretica, 346
Puccinia, 187
Puff balls, 220
Pumpkin, 711
Purslane, 705
Pyrenoid, 2, 3
Pyrenomycetes, 217
Pyrola, 709
Pyrus malus, 681
Pyxidium, 453

Quercus, 669, 704
Quercus macrocarpa, 602
Quillworts, 289–291, 627
Quince, 456

Raceme, 427
Radicle, 99
Ragweed, 711
Rainfall, 477
Rainy-season flora, 569
Ranales, 673, 705
Range, 497
Ranunculaceæ, 673, 706
Raspberry, 454, 455
Red algæ, 171, 628; uses of, 175
Red sage, 572
Redwood, 538
Reed-grasses, 625, 626
Reproduction, 137, 143, 149, 154, 155, 179, 185, 186
Respiration, 110–116, 117
Rhamnales, 707, 708
Rhizoids.
Rhizome,
Rhizomorph (rhi[illegible] morph), 89
Rhizophidium, 214, 215

Rhizopus, 177–180, 215
Rhododendron, 531
Rhodomeniales, 175
Rhodophyceæ, 171
Rhus radicans, 416, 707
Rhus trilobata, 569
Riccia, 23, 164, 222–226, 627
Ricinus, 707
Riverweed, 627, 706
Root, function of, 410–418.
Root-hairs, absorption by, 19, 30, 32
Root-hairs, action on soil, 82
Root pressure, 33, 34, 45
Root, structure of, 30, 361, 362
Root tubercles, 92
Roots, kinds of, 415
Rosaceæ, 679, 706
Rosales, 678, 706
Rose family, 679, 706
Rosette, 405
Rosette plants, 580, 581, 584, 585
Rubiales, 711
Rudbeckia, 712
Ruppia maritima, 618
Ruppia occidentalis, 563, 702
Russian thistle, 705
Rusts, 187–194

Sage-brush, 559, 560, 570
Sahara desert, 574
Salicaceæ, 667, 704
Salicornia, 618
Salicornia herbacea, 563, 705
Salix, 667, 704
Salix adenophylla, 594
Salix glaucophylla, 594
Salix polaris, 583
Salsify, 711
Salsola kali, 705
Salsola tragus, 705
Salt-basins, 563
Salt-bushes, 572
Salt-marsh, 617
Salt-ponds, 623
Saltwort, 590, 591, 705
Salvinia, 627
Salviniaceæ, 296
Samara, 451
Sandalwood, 705
Sand-cherry, 590, 50
Sand-dunes, 56
Sand-hills, 56
Sanguin
, 704
Sap, rise of, 53, 54
Sapindales, 685, 707
Saprolegnia, 181–184
Saprolegniales, 215
Saprophytes, 83–85
Sarcobatus, 564, 572
Sargassum, 170
Sarracenia purpurea, 610
Sarraceniales, 706
Sarsaparilla, 708
Saxifraga oppositifolia, 583
Saxifrage, 706
Scavengers, 554–555
Schizæaceæ, 295
Schizocarp, 451
Schizomycetes, 164
Schizophyceæ, 163
Sclerenchyma, 356–357, 361, 363
Scouring-rush, 282
Screw-pine, 409, 702
Scrophulariaceæ, 696, 710
Sea-beach panicum, 599
Sea-blite, 590
Seacoast marsh-elder, 599
Sea-grass, 628
Sea-oats, 599
Sea-purslane, 590
Sea-rocket, 590, 591
Seaside-spurge, 590
Sedge family, 659, 702
Sedges, 607, 625
Seed, dispersal of, 458–463
Seed plants, 338
Seed, structure of, 98, 102
Seedlings, 97–107
Seeds, 330–334, 507
Selaginella, 286–288, 292
Selaginellaceæ, 296
Semiaquatics, 625, 626
Sensitive fern, 273
Sensitive plants, 132, 396, 399
Sequoia sempervirens, 538, 539
Sequoia washingtonia = S. gigantea, 534, 539–541
Sesuvium maritimum, 590
Sexual organs, 144, 147
Shadbush, 707
Shepherd's purse, 676, 706
Shoot, floral, 419, 432
Shoots, 353–355; types of, 365–373; winter condition of, 374–377
Sieve tissue, 358, 363
Sieve tubes, 52, 53
Silique, 453

Silk-cotton tree, 417
Silver bell, 710
Siphoneæ, 146, 162
Skunk's cabbage, 439–442
Slime molds, 83
Smoke-tree, 707
Snow covers, 472
Societies, 522, 526, 527
Sod-formers, 558, 559, 56.
Solanum, 710
Solidago, 712
Sourwood, 709
Spadix, 428
Spartium, 446
Spathyema fœtida, 438, 662, 703
Spermagonia, 190
Spermatophyta, 653
Spermatophytes, 338
Sphacelaria, 168
Sphærella lacustris, 158, 159
Sphærella nivalis, 158, 350
Sphæriales, 218
Sphagnales, 248
Sphagnum, 164, 608–615
Spiderwort, 11, 703
Spike, 428
Spinifex squarrosus, 592
Spirodela polyrhiza, 27
Spirogyra, 1–5, 13, 14, 60, 72, 136–140, 350, 626
Sporangia, 178–182
Sporangium, 253–258, 281, 290
Spores, 225, 256–258, 263, 264, 281
Sporobolus asperifolius, 558
Sporocarp, 173
Sporogonium (spo''ro-go'ni-um), 224, 231, 233, 234, 237, 238, 239, 241, 246, 247, 248
Sporophyll, 274, 281, 292
Sporophyte (spo'ro-phyte), 225, 226, 232, 234, 237–239, 241, 242, 250, 261, 268, 270, 283, 292, 294, 314, 315, 317, 336–339, 340–348, 434
Spurge family, 707
Squash, 711
Staminodium, 446
Starch, formation of, 68, 70–74; changed to sugar, 77, 78; translocation of, 73; digestion of, 75
Stems, types of, 365–373
Stems, woody, structure of, 381–382
Stipa spartea, 561
Stoma (pl. stomata) (sto'ma-ta), 42–44, 46
Strand formations, 586
Strawberry, 455, 680, 706
Stress, lines of, 504
Strophostyles helvola, 591
Succulents, 394, 395, 580
Sugar-maple, 685
Sugar, test for, 75, 76
Sumac, 707
Sundew, 133, 610, 706
Sunflower, 399–401, 712
Swamp, 606
Swamp societies, 620
Sweet gum, 706
Symbiosis, 85, 86, 92–95, 480
Synergids (syn'er-gids), 327, 330
Syngenœsious, 424
Synthetic assimilation, 67

Tamarack swamps, 616
Tape-grass, 702
Taraxacum densleonis, 700, 711
Taxonomy, 652
Taxus, 534
Teasel, 711
Telegraph-plant, 399
Teleutospore, 188
Temperature, 134, 135, 468, 479, 501, 507, 623, 624
Tetrasporaceæ, 161
Tetraspores, 173, 174
Thallophyta, 653
Thallophytes, 352
Thallus, 352
Thelephoraceæ, 219
Thickets, 516, 530, 704
Thistle family, 697, 712
Thunderwood, 707
Thyrsus, 427
Tilia, 708
Tillandsia, 491, 703
Tissue, tensions of, 57–59
Tissues, classification of, 363, 364; kinds of, 356–359; organization of, 356–362
Toad-flax, 696, 710
Tomato, 710
Tradescantia, 703
Tragopogon, 711
Trailing arbutus, 709
Trailing wild bean, 591
Trametes pini, 90
Transpiration, 35–46
Tree growth, northern limit, 576, 577
Trees, longevity of, 532–534

Tremellales, 218, 219
Triadelphous, 425
Trichodesmium erythræum, 622
Trillium, 318–322, 648, 656, 703
Trillium grandiflorum, 520
Tropical forests, 541
Tropophytes, 485, 493, 494
Trumpet-creeper, 711
Tuberales, 217
Tubers, 373
Tumbleweeds, 507
Tundra, 516, 578
Tupelo gum, 538
Turgescence, 14, 15
Turgor, 20; restoration of, 56, 57
Typha, 606, 625, 702

Ulmaceæ, 672, 704
Ulmus americana, 672, 673, 704
Ulothrix, 162
Ulotrichaceæ, 162
Ulvaceæ, 162
Umbel, 428
Umbellales, 692, 708
Umbelliferæ, 692, 708
Uniola paniculata, 599
Upland forest, 537
Uredinales, 218
Uredineæ, 187–194, 218
Uredospore, 189
Uromyces caryophyllinus, 87
Urticales, 672, 704
Ustilaginales, 218
Ustilagineæ, 218
Utricularia, 610, 711

Vaccinium, 709
Vacuoles, 7, 8
Valerianales, 711
Vallisneria spiralis, 492, 702
Variation, 338
Vascular tissue, 358, 363
Vaucheria, 142–146, 626
Vaucheriaceæ, 162
Vegetation elements, 497
Vegetation formations, evolution of, 605, 606
Vegetation forms, 525
Vegetation of hot springs, 624; of rocky places, 600–606; of swamps and moors, 606–615; of the strand, 586–599
Vegetation regions of the earth, 638–641
Vegetation types, 464, 465, 482, 496
Venus' flytrap, 133, 611
Verbascum, 710
Verbena, 710
Vernal flora, 562
Vessels, 52, 53
Vetch, 92, 707
Viburnum, 711
Vicia sativa, 459
Viola cucullata, 436, 687
Violaceæ, 687, 708
Violet family, 687
Virgin's-bower, 462, 463
Vitaceæ, 707
Volvocaceæ, 158

Walnut, 452, 704
Water, 465; flow of, in plants, 53, 54
Water-fern, 627
Water-lilies, 606, 625, 627, 705
Water-plantain, 702
White pine, 396
White sage, 572
Wild carrot, 691, 708
Willow family, 667, 704
Willows, 595
Wind, 471
Wintergreen, 709; leaf of, 43
Witch-hazel, 706
Wolffia, 28
Wood-destroying fungi, 553–555
Woodland formation, 516, 526, 529

Xerophytes, 483, 485, 565, 590–599, 618
Xerophytic structures, 487, 495
Xerophytic vegetation, 590, 594
Xylem, 50, 52, 360, 361, 363
Xylogen, 92
Xyridales, 703

Yeast, 216; fermentation of, 115, 116
Yucca, 394, 560, 569–572, 703

Zamia, 313, 316, 457
Zannichellia, 627
Zones, 525; of water vegetation, 625
Zoogonidia, 143, 149, 178–184
Zoospore, 149, 154
Zostera, 628
Zygomycetes, 215
Zygospore, 2, 138–140, 157, 160, 179, 180
Zygote (zy'gote), 138, 179

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